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THE LAHAVE RIVER: PHYSIOGRAPHY AND POTENTIAL FOR ATLANTIC SALMON PRODUCTION

by

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ABSTRACT

Gray, R.W., J.D. Cameron, and E.M.J. Jefferson, 1989. The LaHave River: physiography and potential for Atlantic Salmon production. Can. Tech. Rep. Fish. Aquat. Sci. No. 1710.

An extensive Atlantic Salmon enhancement project was undertaken on the Main Branch of the LaHave River above Morgan Falls beginning in 1969. This report describes the involvement of the Department of Fisheries and Oceans in improving fish passage on the river and outlines some of the physical, biological and chemical characteristics of the watershed. Data on stream obstructions, stream profiles, water discharge, water temperature and water chemistry are presented. Atlantic salmon spawning and nursery habitat are classified according to type, measured quantitatively, and described for each major salmon producing tributary of the river.

RESUME

Gray, R.W., J.D. Cameron, and E.M.J. Jefferson, 1989. The LaHave River: physiography and potential for Atlantic Salmon production. Can. Tech. Rep. Fish. Aquat. Sci.. No. 1710.

En 1969, un projet de mise en valeur du saumon de l'Atlantique a été mis en oeuvre dans la rivière LaHave en amont des chutes Morgan. Le présent rapport décrit la participation du ministère des Pêches et des Océans en vue d'améliorer le passage du poisson dans la rivière et il présente certaines caractéristiques physiques, biologiques et chimiques du bassin hydrographique. Des données sur l'obstruction à l'intérieur du cours d'eau, sur la pente, le débit, la température de l'eau et la composition chimique de l'eau y sont également présentées. Pour chacun des principaux tributaires de la rivière produisant du saumon, les habitats pour le frai et l'élevage du saumon de l'Atlantique sont classifiés en fonction des genres, ils sont mesurés sur le plan quantitatif, et ils sont décrits.

INTRODUCTION

This report provides information on the involvement of the Department of Fisheries and Oceans in improving fish passage for Atlantic salmon on the LaHave River, Nova Scotia; describes important physical, chemical and biological characteristics of the river; and details the results of stream habitat surveys to identify salmon spawning and nursery habitat in the tributaries.

WATERSHED DESCRIPTION

The LaHave River (Fig. 1) flows southwest through the counties of Lunenburg, Kings and Annapolis into the Atlantic Ocean at Bridgewater, Nova Scotia (44° 14' N; 64° 20' W). The river has a meander length of 92 km, drains an area of approximately 1668 km^2 and has an average gradient of 2.64 m/km. The watershed contains over 113 lakes with a total surface area of 7516 hectares. The river consists of five major tributaries: West Branch, North Branch, Main Branch, Ohio River and North River.

The West Branch enters the LaHave River 8.8 km above tidewater, has a drainage area of 178 km^2, and a meander length of approximately 34.9 km. The North Branch enters the LaHave River at Wentzell's Lake, has a meander length of 52.5 km and an estimated drainage area of 453 km^2. The Main Branch is approximately 74.4 km in length, has a drainage area of 190 km^2 with a headwater elevation of 228.6 m and an average gradient of 2.64 m/km. The Ohio River has a meander length of 38 km, a drainage area of 190 km^2; and enters the LaHave River at New Germany Lake, 29 km above tidewater. The North River enters the LaHave River 35 km upstream of tidewater, has a meander length of 41 km and an estimated drainage area of 188 km^2. Length, width, gradient and drainage areas of these tributaries are summarized in Table 1. A list of the lakes on each tributary and their respective surface area is given in Appendix 1.

The LaHave estuary is 17.5 km in length and up to 600 m in width. A narrow navigational channel averaging 7 m in depth is maintained to Bridgewater and tidal influence extends to Cooks Falls at the head of tide. The influence of the river drops off sharply about halfway into the estuary with flocculation and deposition of fine suspended material occurring over a relatively short distance. The flocculation zone moves seaward during periods of high river flow.

The drainage basin lies in sedimentary rocks of the late Precambrian known as the Meguma (or gold-bearing) group. From tidewater to New Germany Lake the river flows through rocks of the Halifax Formation consisting

mainly of slate, siltstone and rare limestone at the base. The upper watershed passes through a thin wedge of bedrock strata known as the Goldenville Formation consisting of greywacke and slate. However, the major portion of the upper basin originates in Plutonic rocks consisting of monzogranite and granodiorite. The hard rocks of these two formations yield water with low conductivity. The river water is highly coloured and has a total hardness of 5-8 mg/l ($CaCo_3$ equivalent) with maximum hardness occurring during periods of minimum flow.

Considerable agricultural land exists along the river valley and on the shores of the tidal zone; forests cover the balance of the drainage area. Mixed farming is conducted along the lower river valley and the estuary shores, otherwise, land use is restricted to timber and pulp cutting with some local sawmills and secondary industry based on the lumber produced. The estuary is used as a transportation artery by oil tankers which enter several times a year with loads of 400-500 tons. Lumber products are mainly transported by rail or truck. The lower estuary is used by fishing vessels and, in season, pleasure craft are found throughout the estuary.

The river is relatively unpolluted above tidewater except for sewage disposal at New Germany, and sewage and industrial pollution with heavy metals in the Bridgewater area.

HISTORICAL BACKGROUND ON RIVER OBSTRUCTIONS

Several attempts were made in the 1950's and 1960's by both federal and provincial authorities to rehabilitate parts of the LaHave River. Stream clearance work was conducted during the period 1957-63 to remove minor obstructions, eliminate sawdust pollution and remove debris from the river.

Flow control was proposed for the river on different occasions, however cost was prohibitive and consequently, except for a series of experiments carried out by Hayes (1953), it was not implemented.

A number of natural and man-made obstructions have plagued the LaHave River over the years. On the Main Branch, Cooks Falls (km 2.4) were blasted in 1960 by provincial authorities to facilitate the passage of anadromous fishes at low flow periods; Frideaux and Darr Falls commonly referred to as Mossman rapids (km 9.0) on the Main Branch at its confluence with the West Branch presents a minor problem at extreme low water conditions. The Wentzell Lake dam (km 13.5) located below Wentzell Lake had a functional fishway installed during its operational days which was used by the Department of Fisheries for enumerating salmon and by Dr. F.R. Hayes as a "freshet" dam during his experiments from 1947-54. However, this structure was later breached by residents who claimed their adjacent farmland was flooded, and it was finally removed by the Department of Fisheries. The Parnell Dam located on the crest of Morgan Falls (km 25.3) was originally constructed to operate a water powered pulp mill known as Parnell Mill. It was equipped with a fishway,

however, the control of fishway discharge was seldom satisfactory. Although the fishway was rebuilt in 1956, the Parnell Mill ceased operations in 1958 and the water level behind the dam was lowered making the fishway inoperative. It was partially breached in 1960 and in 1969 the Department of Fisheries and Forestry removed Parnell Dam and constructed a new vertical slot fishway to provide access to the excellent salmon habitat found upstream (Millen 1971; Gray 1974, 1981). Zwicker Dam located at New Germany (km 26.6), used to operate a box mill, was originally constructed with fish passage facilities. However, after the Parnell Mill ceased operations in 1958 and the Morgan Falls fishway became inoperative, maintenance on the Zwicker Dam was discontinued. Later, in 1969, when the new vertical slot fishway was constructed at Morgan Falls, the Department undertook negotiations with the owner of the Zwicker Dam and it was removed during the winter of 1969 (Millen 1971). The Sink Spout or Cherryfield Falls located at km 37.6 originally was a total barrier to anadromous fish; however, in 1957 the Department of Fisheries blasted a channel through bedrock thereby making it passable. Several other timber dams located in the headwaters were systematically removed in the early 1960's to provide fish passage. Although two natural barriers on Sixty Brook were blasted in 1957, a minor natural obstruction still exists particularly during low flows.

On the West Branch, twelve obstructions (mainly dams) were present in 1945. These were gradually removed, and in 1949, the remaining five dams were breached to provide fish passage. By 1954, only Hirtle Falls and Crouse Dam remained as partial obstructions - the latter was able to pass fish when the gates were opened. Although several natural falls or rapids exist on the West Branch which provide salmon with some difficulty during low water conditions, the most significant barriers are two unnamed natural falls located 17.5 km downstream of Hirtle Falls.

On the North Branch, several old dams existed which were systematically removed when they became inoperative. Mulbury dam was removed in 1954 and an old dam at Sherbrooke Lake, used from 1947-51 to create artificial freshets (Hayes 1953), has deteriorated since these experiments. Fish passage problems do not exist at high flows but at low flows, water percolated through the rocks left in the old crib work rather than through the control channels thereby causing a partial obstruction. Indian Falls, located 2.2 km downstream of Texas Lake, existed as a partial barrier for many years. During periods of higher flows, salmon were able to leap the falls, however, in order to improve fish passage over a wider range of river flows and reduce poaching, a fishway was constructed in the early 1950's (Edwards 1954, 1957). This fishway was modified several times with major improvements and reconstruction occurring in 1964 and during the winter of 1977-78. The recent modifications to the Indian Falls fishway included the addition of an entrance pool complete with a water attraction pipeline and diffusion chamber to provide effective fish passage. Beaver dams and mill debris have been prevalent throughout the headwater basin of the LaHave River including this tributary. Many of these were removed during the stream clearance program undertaken from 1957-61.

The Ohio River was extensively used for log driving in the early 1900's. Old dams once used for this purpose have since been removed and no longer pose fish passage problems. One of the last dams to be removed on the Ohio River was Langelle dam which was breached in 1957 - no known fish passage problems presently exist on the tributary.

Three old dams existed on the North River tributary in 1925. These obstructions were removed between 1957-61 as part of the LaHave River clearance program. A natural barrier known as Apron Rock located 6.4 km upstream from the confluence with the Main Branch of the LaHave River prevented salmon from ascending to the headwaters of the North River. A channel was blasted in 1957 on the right bank of the river and a rock diversion dam was constructed to divert water at low flows through this channel thereby providing a bypass to the Apron Rock (Edwards 1957). Although this work improved fish passage at higher flows, it did not provide effective passage at low flows. This partial obstruction still exists at Apron Rock and further work is needed at the site to improve fish passage.

Fish passage problems still exist in the LaHave River watershed. A partial natural barrier still exists near the mouth of Sixty Brook despite attempts to improve fish passage in 1957. Three known natural obstructions still exist on the North River - the falls above the highway bridge, Apron Rock, and the falls immediately below Peter Veinot's stillwater. The first falls is a partial obstruction under normal water conditions and a complete barrier during low flow conditions. The second falls, Apron Rock, is also considered to be a partial obstruction under normal flows and a complete barrier at low flows. The third falls, below Peter Veinot's Stillwater, is a partial barrier to fish movements. On the North Branch, remnants of the crib work from the old Sherbrooke Lake Dam cause a partial obstruction to fish passage during low flow conditions. On the West Branch, a number of rough sections are partial obstructions to fish passage at low flows, particularly two unnamed falls located downstream from Hirtle Falls. Major obstructions at Morgan Falls (Fig. 2) and Indian Falls (Fig. 3) have been equipped with fish passage facilities. Several beaver dams exist in various tributaries of the LaHave River. These potential fish passage problems should be investigated individually to correct impedance to upstream migration and permit salmon access to important spawning and nursery habitats in these tributaries.

MATERIALS AND METHODS

Stream Characteristics -

Water temperature and chemistry (ph and conductivity) data were collected at various locations throughout the drainage basin. Water temperature data were collected using Taylor maximum-minimum thermometers, Ryan continuous recording thermometers, hand held and pocket thermometers. All instruments were checked for accuracy against mercury thermometers.

Data on pH and conductivity were collected from each of the five major tributaries and at various locations throughout the drainage basin. Measurements of pH were made using a Metrohm pH meter equipped with a glass electrode. The meter was calibrated each time before use with buffer solutions. Conductivity was measured with a YST 33 S.C.T. meter equipped with a plastic electrode. This instrument was accurate to ± 3% at mid-scale on the meter.

Water velocity data were collected during October 1981 at selected locations coincident with salmon spawning and nursery habitat studies. A Price 622AA current meter was used to determine velocity. Three velocity readings were measured at two sites within each location usually 30 m apart along the center line of the stream.

Stream gradients in selected types of habitat were calculated using a surveyor's level and rod with elevations being recorded every 15 m along the center of the stream bottom for 100 m at each location. Topographic maps (1:50,000) and data from Jefferson (1968) were used to complete the upper basin profile.

Atlantic Salmon Habitat -

Salmon habitat surveys were conducted seasonally from mid-May to mid-September 1976-81. Topographic maps (1:50,000) were used to divide the river and its tributaries into 1 km sections for study. Each section was identified by an alphanumeric code and given a number starting at its mouth. These stream sections were further subdivided into 100 m stream units and given a number starting at the downstream end of the unit. Land marks were used as reference points to verify locations and correct any discrepancies from topographic maps.

Stream length measurements were made using an optical range finder, Model 620 Opti-Meter calibrated from 15-180 m; manufacturer's state accuracy ranged from 99 to 96% for the extreme ranges of the meter. Stream widths were taken using different optical range finders, Model 100 calibrated from 2 - 30 m or Model 120 calibrated from 6 - 100 ft; manufacturers' stated accuracy ranged from 99% to 97% for the extreme ranges of the smaller meters. The optical range finders were calibrated routinely on a daily basis using a surveyors' steel chain.

Three width measurements were taken in each stream unit (100 m). Depths in each unit were recorded at three points across the stream at the beginning, mid-point and end of each unit.

Observations were made in each 100 m stream unit to estimate and identify bottom composition as percentages of silt, sand, gravel, cobble, boulder and bedrock. The surface areas of riffles, runs, and flats were recorded as percentages of the stream unit. If bottom composition changed significantly

within the stream unit, the unit was subdivided and each bottom type measured separately. Measurements were taken using optical range finders, and in the larger stillwater sections, lengths were determined from topographic maps.

The following definitions were used to describe bottom substrate in the stream habitat surveys:

Substrate type	Particle Size (cm)
Silt	Small grade sand or washed out topsoil (under 0.1)
Sand	0.1 - 0.5
Gravel	0.6 - 10.2
Cobble	10.3 - 30.5
Boulder	over 30.6
Bedrock	Outcroppings of exposed bedrock or ledge

Stream characteristics were defined as follows:

Riffle:	shallow, fast flowing broken water (over 20 cm/sec velocity; 10 to 40 cm depth)
Run:	deep, fast flowing unbroken water (over 60 cm/sec velocity; over 40 cm depth)
Flat:	shallow, slow flowing section with cobble/boulder substrate and various types of overhanging cover
Pool:	deep, slow flowing sections with boulders, logs or overhanging stream bank vegetation as cover
Stillwater:	deep, slow flowing sections with silt or mud, i.e., soft substrate with little cover except along the stream banks

Spawning Habitat -

Spawning areas were classified as "good" or "marginal" based on substrate composition, water depth, velocity and knowledge of areas where salmon spawned during the study. Consistently high fry densities, in electrofishing surveys, were found in proximity to good spawning habitat

whereas marginal spawning areas were utilized less and exhibited lower fry densities when sampled each July. Trubutaries with significant fluctuations in water level, partial barriers or low pH were excluded from the analysis made to establish criteria used to classify spawning habitat.

Ten spawning areas consistently used by salmon with resultant high fry densities in proximity to the spawning sites were examined to establish criteria for evaluating spawning habitat. Good spawning habitat was associated with the following characteristics:

Substrate Compositions: 5 -10% sand (mean 6.4); 40-80% gravel (mean 58.0) ; 10-40% cobble (mean 11.7).

Stream Characteristics: 0.33-1.00% gradient (mean 0.68) 30-48 cm depth (mean 35.0); 50-100% riffle (mean 71.0); 5-40% run (mean 17.0); 58-98 cm/sec velocity (mean 78.0).

Good spawning habitat was defined as those areas which had less than 10% sand; 40-80% gravel with 10-40% cobble and occasional boulders (less than 20%); stream velocities of 58-98 cm/sec and stream depths of 30-48 cm at spawning; stream gradient were usually greater than 0.5% and stream sections consisted of at least 50% riffle and run.

Marginal spawning areas utilized by salmon usually had more than 10% but less than 20% silt and sand, less than 40% gravel, with higher cobble/boulder composition (50-90%), and less than 50% riffle. These marginal areas usually had extremes in velocities and gradients and consisted of a higher proportion of runs. Spawning habitat where substrate vegetation exceeded 20% were also considered marginal spawning areas. These areas had either high water velocities which could cause redd wash-outs or were too slow to provide adequate water flow through the redd. Areas where water depth exceeded 1.0 m, regardless of substrate composition, were considered unsuitable for spawning.

Nursery Habitat -

Nursery habitat refers to habitat utilized by underyearling parr (0+) and yearling parr (1+) stages. Nursery habitat was classified as "good", "fair", or "marginal" based upon parr densities and associated stream characteristics found during annual electrofishing surveys. Stream characteristics associated with highest parr densities were used to define good parr nursery habitat, as follows: cobble/boulder composition equal to or greater than 50% of the section where cobble made up at least 20% of this substrate mixture, where at least 70% of the section consisted of riffle and run, and where water depth was at least 18-20 cm.

Stream characteristics where moderate numbers of salmon parr were found during electrofishing surveys were assumed to represent fair parr habitat. Fair habitat was defined as shallow stream areas where the combined cobble/boulder composition ranged from 10-49%, usually with a minimum of 10% cobble in the mixture; where gravel made up at least 50% of the substrate and where at least 70% of the stream section consisted of riffle and run.

Marginal parr nursery habitat consisted of stream areas where the combined cobble/boulder composition was less than 10%, or areas consisting of flats, pools, stillwaters, or lakes which could provide important rearing refuges for young salmon under low water conditions or in situations of overcrowding.

RESULTS AND DISCUSSION

Stream Profile

A stream profile of the LaHave River including its major and some minor salmon producing tributaries is summarized in Table 2.

The lower section of the Main Branch of the LaHave River between Wentzell's Lake and the head of tide has a moderate gradient (2.58 m/km) (Table 2) consisting of deep runs, pools and large stillwaters. As described previously, there are two falls in this section, Cooks Falls and Frideaux Falls, which would be considered partial obstructions during extreme low flow periods. The bottom substrate in this section consists largely of cobble, boulder with bedrock in the steeper gradient sections and cobble combined with fine gravel to coarse sand in the lower gradient sections. The Main Branch of the LaHave River from Wentzell's Lake to Morgan Falls is a low gradient section of river (1.04 m/km) consisting mainly of runs, riffles and pools. The bottom substrate is predominantly cobble and gravel with large amounts of sand and silt present in the stillwater areas. Morgan Falls, a 6.1 m natural falls, is equipped with a vertical slot fishway to provide fish passage for freshwater, anadromous and catadromous species. The average gradient of the Main Branch of the LaHave River from Morgan Falls to the headwaters (Cloud Lake) is moderate (3.00 m/km). The substrate in the steeper gradient areas is composed of various amounts of gravel, cobble and boulder while the substrate found in stillwater areas is mainly a mixture of cobble, gravel and coarse sand. There are large areas of stillwater in this section of river; however, the sections in steeper gradient areas consist largely of riffles, runs and small pools. Several headwaters tributaries to the Main Branch of the LaHave River are relatively fast, steep gradient streams: Mason Meadow Brook (8.05 m/km); Sixty Brook (6.54 m/km); Thirty Brook (5.41 m/km); Shellcamp Stream (5.03 m/km) and Spry River (8.13 m/km) (Table 2).

The West Branch of the LaHave River from its confluence with the Main LaHave River to Hirtle Lake is a low gradient stream (1.91 m/km) (Table 2). The steeper gradient sections of this stream consist mainly of riffles, shallow

runs and small pools, while the low gradient sections consist mainly of flats. Substrate composition in the steeper gradient sections is a mixture of gravel, cobble and boulder while in the low gradient sections substrate composition consists mainly of gravel, sand and silt. As already described, there are three natural falls on this system - Hirtle Falls and two unnamed falls.

The North Branch of the LaHave River from Wentzell's Lake to Sherbrooke Lake is a moderately fast flowing section (4.67 m/km) with alternating runs, riffles and pools. Substrate composition is primarily cobble and gravel although there are sections of the river where substantial amounts of boulder and bedrock are present. Indian Falls, a 4.9 m natural falls, is equipped with a modified vertical slot fishway. The headwater tributaries of this branch include the Sherbrooke River (5.43 m/km), Lake Paul Brook (2.86 m/km) and the Gully River (8.32 m/km) which are moderate to fast flowing streams with alternating runs, riffles, and pools (Table 2). There are several large stillwater areas located in these streams and substrate composition in these areas consists mostly of gravel and coarse sand.

The Ohio River, a tributary to the main LaHave above Morgan Falls, is a moderately fast flowing river (6.52 m/km) (Table 2). Substrate composition primarily consists of gravel, cobble and boulder material. Alternating runs, riffles, small pools and stillwaters are present in this stream. Major obstructions do not exist on this river. Little River, a tributary of the Ohio River, is a fast flowing stream which is steeper in gradient than the Ohio River itself (11.27 m/km). The substrate composition of Little River consists primarily of gravel, cobble and boulder which combined with runs and riffles would provide good nursery habitat for salmon. Low pH in this tributary however, is presently a biological constraint to the full utilization of its production potential.

North River is a tributary which enters the Main LaHave River above Morgan Falls. North River can be classified as a moderate to fast flowing river (4.01 m/km) (Table 2) consisting of rapids, runs and riffles, especially in its lower sections. Substrate composition in these areas consists of a mixture of gravel, cobble, boulder and bedrock. As described previously, there are three natural obstructions on North River. There are five major stillwater areas on the North River. Substrate composition in low gradient sections of the stream consists primarily of gravel and coarse sand with some boulders. Nimchin Brook a tributary to North River has a relatively steep gradient, 5.85 m/km (Table 2).

Stream Discharge

Two water guaging stations have been operated on the LaHave River by the Water Resources Branch, Inland Waters Directorate, Environment Canada. The uppermost guaging station, located above Morgan Falls at the Osburne Road Bridge (44º 32' 49"N; 64º 43' 02"W), records stream discharge from the upper watershed (728 km^2) including the Main Branch, Ohio River, North River and several minor streams. This station was operated from August 1915 to

June 1917, and later from June 1963 to April 1979 when its operation was discontinued. A second water guaging station, located at West Northfield, below Bruhm's Bridge (44° 26' 48"N; 64° 35' 30"W), records discharge from all branches of the river (1250 km^2) except the West Branch of the LaHave River. This station has been operated continuously from July 1915 to the present.

Daily water discharge (cfs) data from the Osburne guaging station located immediately above Morgan Falls are summarized in reports on surface water data in the Atlantic Provinces published by the Inland Waters Directorate, Water Resources Branch, Water Survey of Canada for the years 1965-79. Mean monthly discharge data for a ten year period, 1970-79, indicate that significant fluctuations in discharge occur throughout the year (Table 3; Fig. 4). Low flows (cfs) normally occur during the months of July (222.5), August (249.6), and September (208.8) while the highest flows were recorded during the months of December (1262.9), January (1166.4), March (1319.3) and April (1531.1) (Table 3).

Daily water discharge (cfs) data at the West Northfield guaging station are also summarized in reports on surface water data in the Atlantic Provinces published by the Inland Waters Directorate, Water Resources Branch, Water Survey of Canada for the years 1965-80. Mean monthly discharge data for an eleven year period, 1970-80 are shown in Table 4. Although mean monthly discharges were higher at West Northfield reflecting the influence of drainage from the North Branch, the same annual flow pattern was exhibited at this guaging station as at the Osburne Station. Low flows (cfs) were recorded during the months of July (390.7), August (443.6) and September (344.1); the highest flows were recorded in December (2071.9), January (1881.4), March (2120.2) and April (2439.9).

In order to obtain discharge information at the old Sherbrooke Lake dam on the North Branch, MacLaren Atlantic Ltd. (Anonymous 1976) assumed similar meteorological conditions throughout the LaHave watershed. Using discharge data from the West Northfield guaging station and the "area proportion method", the consultants estimated discharge. Since the drainage area above the old Sherbrooke Lake Dam was 290 km^2 relative to a drainage of 1250 km^2 above West Northfield they concluded that discharge would be about 23% of that at West Northfield. The consultants calculated that flows of 40-50 cfs would be suitable during the summer months for fish fauna in this part of the river, recognizing that flow requirements to stimulate adult ascent and smolt emigration would be higher.

Jefferson (1968) reviewed stream discharge in detail for the LaHave River and calculated the probabilities for flooding and extreme low flows from the discharge data from guaging stations at the Osburne Bridge at Morgan Falls and West Northfield. He predicted an 80% probability that stream discharge would exceed 11,000 cfs once in every five years. Extreme low flows of 20 cfs on the other hand had an 80% probability of occurrence once in every five

years. The runoff pattern from mid-winter and spring thaws causing snow melt produce high discharges over a longer time frame than singular rainfall occurrences during the summer months.

Jefferson (1968), using a hypothesis for channel storage and other potential artificial water storage areas, examined the feasibility of flow control in several parts of the LaHave watershed, including channel sections such as Texas and Indian Lakes on the North Branch, and the Main Branch between New Germany and West Northfield. He also examined the feasibility of potential lake storage areas for flow control and suggested that the Big LaHave, Shell Camp and Cloud Lakes would have potential for storage and flow regulation.

Water discharge on the LaHave River is of vital importance to juvenile salmon production and adult migration patterns. The high probability of extreme low flows (20 cfs) occurring once in every five years and its subsequent effect on juvenile salmon survival and year-class strength suggests that discharge patterns on the river should be considered as a biological constraint in any predictive model used to estimate sustainable stock yields or in projecting individual yearclass strength, stock harvest and spawning escapements.

Water Temperature

Daily water temperatures collected at the Morgan Falls fishway from May to October are summarized in Fig. 5. Mean Daily temperatures in May ranged from 7.1 - 19.3°C. Since mean daily water temperatures reach or exceed 10°C, the temperature at which smolts emigrated on the nearby Medway River (Wykes 1967), and discharges are correspondingly high in early May, it might be expected that smolt emigration on the LaHave River occurs between May 6 - 31 annually. Chadwick (1981) also reported that smolt emigration commenced when minimum water temperatures exceeded 7°C and peaked at 10°C. Smolt trapping was not carried out on the LaHave River to verify smolt migration timing.

Mean daily water temperatures ranged from 16.0 - 20.5°C in June, 20.3 - 23.1°C in July and 20.7 - 23.1°C in August. In a normal year, stream temperatures begin declining in late August and continue to decrease throughout September and October. Mean daily water temperatures ranged from 13.8 - 20.6°C in September and 6.2 - 14.1°C in October. Daily maximum water temperatures recorded from May to October were 15.6, 22.0, 24.6, 24.8, 22.0 and 16.4°C, respectively. Overnight cooling in most instances reduced water temperatures to 20 - 21°C even during periods which exhibited the highest daily maxima. A review of monthly ranges in mean daily water temperatures in the various tributaries is outlined in Table 5.

Water temperature data for the Ohio River were collected from June to November, 1980-81 (Fig. 6). Mean daily water temperatures in the Ohio River exhibited greater variability than on the Main Branch at Morgan Falls. Water temperatures were generally higher during the summer months but declined more rapidly in the September-November period than those at Morgan Falls. This probably reflects the fact that the stream has a higher gradient, is supplied with surface water and is characterized by low summer flows. Mean daily water temperatures ranged from 17.3 - 21.8°C in June, 17.7 - 25.1°C in July, 17.0 - 24.1°C in August, 10.6 - 22.4°C in September, 5.1 - 11.5°C in October and 0.7 - 5.2°C in November in this stream. Water temperature maxima for the months of June, July, August, September, October and November were 23.5, 29.2, 28.4, 25.4, 14.0, and 5.5°C respectively. On days when temperature maxima were near the upper lethal limit of 29 - 30°C for Atlantic salmon (Elson 1975), overnight cooling reduced water temperatures by as much as 9°C, thus prolonged high temperatures were not observed in this study.

Diurnal variation in water temperatures in Sixty Brook are summarized in Fig. 7. Mean daily water temperatures ranged from 14.5 - 22.5°C in July, 16.0 - 24.3°C in August, 7.9 - 22.3°C in September and 6.0 - 13.5°C in October. As in other tributaries, water temperatures commenced their decline in August and continued to decline in September and October.

Mean daily water temperatures in the North River are available for the months of June, July, September and October (Fig. 7). Mean daily water temperatures ranged from 16.5 - 22.3°C in June, 17.8 - 25.3°C in July, 8.5 - 21.3°C in September, and 5.3 - 13.8°C in October.

Mean daily water temperatures in the North Branch at Indian Falls for the months of June, August, September and October are summarized in Fig. 8. Mean daily water temperatures in the North Branch ranged from 15.9 - 20.3°C in June, 17.3 - 24.4°C in August, 13.0 - 17.8°C in September and 6.3 - 14.9°C in October. Water temperature maxima for the months of June, August, September and October were 21.7, 29.4, 20.0 and 17.0°C respectively.

Water temperature data are only available for July and October 1981 in the West Branch of the LaHave River (Fig. 8). Mean daily water temperatures in July ranged from 14.0 - 21.5°C while in October mean daily water temperatures ranged from 3.5 - 10.8°C.

As a general rule, mean daily water temperatures were lower in the headwater tributaries than in the main river and overnight cooling in these tributaries reduced the impact of water temperature maxima observed in July and August. Water temperatures from late August through to October were generally lower in the headwater tributaries than in lower sections of the river. Water temperatures throughout the various tributaries were within the temperature regime (15 - 25°C) reported by Elson (1975) to favour juvenile growth of Atlantic salmon, and permit adults to ascend freshwater streams during the summer months (Elson 1969).

Growth of poikilotherms is directly related to temperature, food availability (Allen 1969) and other factors such as the calcium content of the water (LeCren 1972; Mann 1971). Allen (1941) observed that older smolts were produced at higher latitudes with lower water temperatures. Power (1969) suggested that a summer with at least 100 days at a mean temperature of 6°C or higher was a minimal requirement for Atlantic salmon. At temperatures below 7°C juvenile salmon move from riffles to pools and reduce or cease feeding (Allen 1940; Saunders and Henderson 1969); above 7°C the growth rate of Atlantic salmon fry increases, reaching a maximum at 16.6°C (Siginevich 1967). Since the growth of juvenile Atlantic salmon at temperatures below 7°C is slow (Allen 1941), the growing season in a river may be defined as the number of days per year in which the water temperature reaches or exceeds 7°C. Although Riddell and Leggett (1981) reported that parr obtained some energy from feeding even at temperatures of 0 - 1°C, these authors did not suggest what temperature was needed to produce a net surplus of energy above maintenance requirements which could be used for growth.

According to Symons (1979) approximately 500 days at or above 7°C are required to produce a 15-cm smolt. In many southern rivers these 500 days at or above 7°C are accumulated in less than 2 years. On the LaHave River, water temperatures exceed 7°C roughly 182 days per year, yet smolt age is predominantly two years (93%) (Gray1986). This implies that the growth rate of wild salmon smolts in the LaHave River may exceed that described by Symons (1979) since roughly 364 days of temperature above 7° occurs over a two-year period.

Under more stressful rearing conditions in a salmon hatchery it has been observed that maximum growth is attained at different temperatures for various juvenile stages (G. Farmer pers comm.)[2]. Farmer observed that 1-2 gm underyearling parr initiate feeding at about 10°C when temperature is increasing; maximum growth is attained between 16 - 19°C with peak growth at about 18°C. Growth rate is depressed in the temperature range 20 - 22°C since conversion efficiency decreases and metabolic expenditure increases although feeding may continue at a high level. For 7-gm underyearling parr maximum growth rates were observed between 16 - 18°C with peak growth occurring at about 17°C. A dramatic slowdown in growth was observed at 22°C although feeding continued at a high rate suggesting that metabolic expenditure equalled the energy of the food consumed and consequently was not converted to growth. For 30-gm underyearling parr maximum growth was attained at temperatures ranging from 15 - 17°C with peak growth occurring at about 16°C - virtually no growth was observed at 22°C.

Based upon reported feeding temperatures, the growth period for young salmon in the LaHave River and its tributaries would generally start in early May with more rapid growth occurring during June as water temperatures reach

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16 - 19°C. Juvenile salmon growth would be expected to slow down in July and August and even cease when water temperatures exceed 22°C. Growth should increase again in September with relatively constant water temperatures between 15 - 17°C but decline slightly in October as temperature decreased. Overall, rapid growth should occur for at least 40 days during the period from May to October with smaller growth increments achieved at temperatures between 7 - 14°C and 18 - 21°C.

Water Chemistry

Stream pH and conductivity data for various tributaries of the LaHave River, collected in late July 1980, are summarized in Table 6. Stream pH ranged from 5.58 - 6.18 at various locations on the Main Branch and in its smaller headwater tributaries when sampled in late July 1980. The Ohio River and its two tributaries, Little River and West River, had low pH readings, some below the critical level of pH 5.0 (Farmer et al 1980) - pH in these tributaries ranged from 4.70 - 5.36. The North River had pH levels ranging from 5.80 - 6.31, however, in Bob and John Brook the pH was more acidic (4.90). The West Branch had pH values ranging from 5.12 - 6.02 when sampled in July 1980. The pH in the North Branch was above critical levels ranging from 5.15 - 6.10; Gully River had the lowest pH (5.15) on the North Branch. Data on stream pH collected in June 1981 corroborated that recorded in July 1980. The Ohio River and its tributaries had pH values ranging from 4.54 - 5.23 confirming that acidic conditions prevail in this stream and therefore represents a serious biological constraint to salmon production.

Monthly variation in pH and conductivity measured at West Northfield on the Main Branch of the LaHave River are summarized in Table 7. None of the pH measurements were below 5.2 and most values were above pH 5.5; pH dropped during the winter months from November - February and again in the spring during April - May corresponding to mid-winter and spring thaws, melting snow and the consequent runoff of acidic substances accumulated over the winter. Data from Thomas (1960) collected in 1954-55 indicate similar trends; however, pH values were higher, ranging from 5.7 - 6.7 with the lowest pH recorded at the end of November (5.8), December (5.9) and March (5.7) on the Main Branch (Table 7). Although pH values in the LaHave River may not appear at first glance to have declined significantly over the last 26 years (mean 6.2 in 1954-55 versus mean 6.0 in 1980 or mean 5.8 in 1981), pH is measured in logarithmic units, hence the observed decrease of 0.2 - 0.4 pH units actually represents a substantial increase in acidity. Also, as the pH value drops, a much greater degree of acidity is required to lower the pH value further (Davis, 1980).

Watersheds vary considerably in their natural buffering capacity because of differing geological and soil characteristics. Soft-water tends to show the effects of acidification more readily than hard-water (Davis, 1980). Studies in Scandinavia (Wright and Gjessin 1976; Dickson, 1975) and various parts of

North America (Beamish 1976; Schofield 1976) including the Maritimes (Watt et al 1979; Farmer et al 1980) suggest that the pH of numerous soft-water lakes and streams have declined over the past few decades.

One of the earliest reports of the effects of increased acidity on salmon was that by Sunde in 1926 and summarized in Leivestad et al (1976). In this study, hatchery mortalities in eggs and newly hatched fry were reduced by filtering water through lime thereby increasing pH. In the southern part of Norway, where acidity levels range as low as pH 4.1, the current yield of salmon is virtually nil compared to other regions of the country where pH levels still run at 5.5 or higher and production shows little impairment (Davis, 1980). Numerous other examples of the deleterious effects of high acidity on aquatic environments have been reported in the literature and were reviewed by Davis (1980). The author provides an exhaustive review of the mechanisms whereby fish populations are affected by increased stream acidity. These effects range from the direct mortality of eggs or juveniles to such indirect effects as disturbances in adult reproductive physiology or behavior, feeding, growth, oxygen exchange over the gills, and in the ion and acid-base balance, particularly salt uptake. Toxic metals whose concentration is increased in acidic waters contribute to the problem. Surveys of streams and lakes in Scandinavia, Great Britain and North America have consistently found fewer individuals as well as fewer species of invertebrates in acidified waters than in comparable non-acidified water bodies according to Davis (1980) thus suggesting that food availability for salmon and subsequently salmon production could be adversely affected by increased stream acidity.

Conductivity was low in all the tributaries, reflecting the soft waters of the LaHave River; it ranged from 19.0 - 31.0 umhos/cm when sampled in July 1980. Thomas (1960) described soft waters as those containing less than 60 ppm total hardness as calcium carbonate ($CaCO_3$). Conductivity ranged from 27.0 - 51.0 over the two-year sampling period at West Northfield with the lowest values corresponding to spring run-off during April, May and early June (Table 7). Water was highly colored by humates in the form of humic and fulvic acids associated with the many bogs and swamps throughout the watershed. The specific conductance measured in umhos/cm averaged 33.1 in 1980 and varied from 28 - 44 at Wet Westfield; the lowest values were recorded in the May-June period (Table 7). In 1981, the mean annual specific conductance was 33.3 and varied from 27 - 51 with the lowest values recorded during the April-June period and in November (Table 7). Specific conductance measurements in the Ohio River, North River, West Branch and North Branch were similar to those recorded on the Main Branch at West Northfield.

Atlantic Salmon Spawning Habitat

Several authors have described Atlantic salmon spawning habitat, including Belding (1934), White (1942), Mills (1973), Peterson (1978), Peterson and Metcalfe (1981), and Jordan (1981). Typical spawning sites were located where water velocity was accelerating and water depth was decreasing in a

downstream direction at the tail of a quiet stretch or pool or in gravel beds near the river bank where aquifers were present. White (1942) suggested that spawning areas were sometimes found in the stream where currents were converging between two obstructions or where it was deflected by a single obstruction. In most instances, the common denominator appears to be a good flow of water with suitable substrate size and substrate permeability. Salmon avoid spawning in very swift water and often abandon redds if heavy rains cause excessive flooding in the selected site.

White (1942) described the structure of salmon redds in the Moser River, Nova Scotia. This author proposed the construction of artificial spawning beds to extend spawning habitat in rivers where suitable gravel types were scarce. White observed that Atlantic salmon would construct redds in a mixture of sand and fine gravel which contained little coarse gravel, however, he did not find salmon spawning in coarse gravel which was free of fine gravel and sand. He reported that a salmon redd varied in dimensions according to the size of the salmon. In redds dug by female grilse or small salmon the pit was not more than 15.2 - 20.3 cm in depth or 45.7 cm in diameter; for large salmon the pit was usually 30.5 cm or more in depth and over 91.4 cm in diameter. At the bottom of the pit was an "egg pocket" which contained several large stones distributed loosely with most of the finer material washed away from them. After spawning the female covered the eggs with loose coarse gravel found upstream of the pit; this material was pushed into the egg pocket over the eggs, and over the large stones at the bottom of the egg pocket. A completed redd had the form of a low mound, longer than wide, with the upstream face having a slope of roughly thirty degrees (White 1942). Fine material was used to cover the redd to create a more or less impervious upper layer over the redd. This upper layer appeared to assist in causing a flow of water through the lower part of the redd consisting of larger stones where the eggs were located. Since the redd was usually located in an area of accelerating current this structure tended to improve circulation and oxygenation of the eggs in the egg pocket.

Peterson (1978) studied the physical characteristics of Atlantic salmon spawning gravel in seven New Brunswick salmon streams. Although Peterson's sampling sites were selected subjectively in areas where water velocity was accelerating and water depth was decreasing in a downstream direction at a tail of quiet stretch or pool, eleven of thirteen sites sampled were actually utilized by spawning salmon. Water depth ranged from 20 - 30 cm and water velocity ranged from 0.36 - 0.76 m/sec with most areas exhibiting a velocity between 0.50 - 0.65 m/sec. Since these measurements were taken within a week of low flow conditions, depths and velocities might be expected to be higher at spawning time. Core samples taken to a depth of 15 cm by Peterson (1978) yielded the following particle size compositions:

Substrate	Size (mm)	Composition (%)
Fine sand	0.06 - 0.5	0 - 3
Coarse sand	0.5 - 2.2	10 - 15
Pebble	2.2 - 22.2	40 - 50
Cobble	22.2 - 256.0	40 - 60

Peterson (1978) found that the gravel types were stratified with finer material found in the deeper sediments. In the top 15 cm, he found that the cobble/pebble ratio was 0.5:2.0, while sand was 10 - 15%; in the lower 15 - 25 cm depth, sand increased to 20 - 30 %. Presumably as the female prepares the redd, this stratification would be altered perhaps in keeping with the redd structure described by White (1942) where larger stones were placed around and under the egg pocket. Water permeabilities were usually less than 2000 cm/hr with observed differences between spawning areas on the Waweig, Digdeguash and St. Croix rivers. Peterson (1978) found that sediments less than 2 mm in diameter were detrimental to permeability and therefore to spawning success. Peterson's data suggest that if the sand content of the natural gravel bar was greater than 20%, permeability was near zero with corresponding redd failure. He suggested that survival would be low with permeabilities of less than 1000 cm/hr corresponding to a sand content of 12 - 15% in the areas he studied. However, since permeability was only weakly correlated with the amount of sand present, sand content by itself cannot be used as an indicator of redd success. The permeabilities of most areas in Peterson's study ranged from 1000-2000 cm/hr, consequently, it is assumed that gravels of higher permeability would produce better fry survival. While the above characteristics were considered typical of good spawning habitat, under less ideal conditions where there are excessive numbers of spawners, less than optimal areas are probably utilized by salmon.

Jordan (1981) carried out Atlantic salmon spawning surveys in five Maine rivers between 1974-78. This author observed that spawning began at water temperatures between 7 - 10.5°C; this temperature regime was considered desirable by Peterson and Metcalfe (1978) for normal alevin development during incubation. Jordan (1981) found that water depth ranged from 22 - 74 cm (average depth 36 ± 1 cm); water velocity ranged from 27 - 83 cm/s (average velocity 49 ± 2 cm/s), and standard permeabilities (k_{10}) ranged from 74 - 4680 cm/hr in the spawning areas. At sites where spawning had occurred the previous year, K_{10} values were higher and ranged from

2500 - 4680 cm/hr since the gravel had been loosened or "worked" by spawning females previously. The mean redd length (2.38 m) and width (1.39 m) was recorded and the actual area occupied by the redd averaged 3.8 m^2 in the five eastern Maine streams studied by Jordan (1981) - this study suggested that each female dug an average of 2 redds.

Spawning areas selected by Atlantic salmon probably vary somewhat in their characteristics. Stream characteristics such as bottom substrate, substrate compaction, vegetation, presence of aquifers, water depth, velocity and substrate permeability are important parameters for successful spawning and fry survival. However, published work does not cover a sufficient range of river types to define accurately the range in spawning habitat types or necessarily what constitutes "good" spawning habitat. Also, other factors including such stock characteristics as spawning behavior, fish size, egg size and others have not always entered the equation. For example, spawning habitat utilized regularly by Atlantic salmon in the Moser River (White 1942) and in some other rivers on the eastern shore of Nova Scotia where self-sustained salmon stocks occur, is different from that utilized in the West St. Mary's, Fifteen Mile stream, or such New Brunswick salmon streams as the Restigouche and Miramichi rivers.

Atlantic salmon spawning areas in this study were categorized as "good" or "marginal" according to substrate composition, water depth, and water velocity. In the spawning areas studied on the LaHave River, it was evident that good habitat had low amounts of sand (6.5% vs 10.1%), higher amounts of gravel (58.0% vs 17.0%), similar amounts of cobble (27.0% vs 24.0%), lower boulder composition (11.7% vs 49.0%), more riffle (71.5% vs 32.5%) and less run (17.0% vs 60%) than in "marginal" spawning areas (Tables 8 and 9). Depth, velocity and stream gradients were higher in marginal habitat than in good habitat (Tables 8 and 9). It appears that spawning areas identified as marginal provide less desirable habitats for spawning and the resultant survival of salmon progeny may be lower. While it is known that spawning habitats as described in this report were utilized by salmon, their effectiveness relative to good spawning habitat is unknown. A comparison of stream characteristics of spawning habitat described by different authors is summarized in Table 10.

According to the criteria used in this study for identifying spawning habitat, the Main Branch and its smaller headwater streams have a total of 132,732 m^2 of good spawning and 267,397 m^2 of marginal salmon spawning habitat (Table 11). This represents 36.1% of the total good spawning area and 40.2% of the marginal spawning area in the LaHave River making the Main Branch the most significant spawning area in the river.

A total of 51,935 m^2 of good spawning and 73,241 m^2 of marginal spawning habitat was observed on the West Branch of the LaHave River (Table 11). This habitat represents 14.1% of the total good spawning and 11.0% of the total marginal spawning habitat for the whole river system.

The Ohio River, one of the major tributaries of the LaHave River, has 55,086 m^2 of good spawning and 87,408 m^2 of marginal spawning habitat, the bulk of which is located between New Germany Lake and West Lake (Table 11). Good spawning areas in the Ohio River represent 15.0% of the total good spawning habitat for the LaHave River while marginal spawning habitat makes up 13.1% of that recorded for the whole river.

The North River has 20,518 m^2 of good spawning and 55,644 m^2 of marginal spawning habitat representing 5.6% and 8.4% respectively of the total good and marginal spawning habitat found in the LaHave River (Table 11).

On the North Branch a total of 107,845 m^2 of good spawning and 181,178 m^2 of marginal spawning habitat was recorded (Table 11). This habitat represents 29.3% of the total good spawning habitat and 27.2% of the total marginal area found in the LaHave River. The majority of the good and marginal spawning habitat was located in the North Branch between Wentzells Lake and Sherbrooke Lake.

In terms of good spawning habitat, the Main Branch (132,732 m^2) ranks first, followed by the North Branch (107,845 m^2), Ohio River (55,086 m^2), West Branch (51,935 m^2) and the North River (20,518 m^2). Of the total spawning habitat recorded for the LaHave River (1,032,984 m^2), 368.116 m^2 or 35.6% was classified as potentially good spawning habitat for Atlantic salmon. The best spawning areas on the LaHave River were found (a) between Indian Lake and Sherbrooke Lake (North Branch), (b) West Branch, (c) from Morgan Falls to the headwaters of the Main Branch (Main Branch), (d) from Wentzells Lake to Morgan Falls (Main Branch), (e) from New Germany Lake to West Lake (Ohio River), (f) from Tidehead to Wentzells Lake (Main Branch), and (g) from Wentzells Lake to Indian Lake (North Branch).

Atlantic Salmon Nursery Habitat

Habitat preferences of various stages of young salmon are different. Elson (1975) reported that young salmon prefer riffle or rapid sections over deep pools and long stillwater sections. However, when populations of young salmon are abundant they can be found in areas normally considered less than ideal. In "rapids" or stream sections with a noticeable gradient indicated by riffles on the surface of the water, salmon parr are sometimes found in water depths of less than 25 cm and in deeper water with mainly gravel (less than 10 cm diameter) and cobble (15 - 30 cm diameter) substrate; however, higher densities of parr were found in cobble substrate (Elson 1975). Elson found that salmon parr were less prevalent in flats and pools; however, shallow flats (less than 25 cm) were utilized more extensively than deep pools (over 100 cm).

Underyearlings were found in abundant numbers over gravel; as they grew larger, they showed a preference for coarser bottom, particularly cobble (15 - 30 cm diameter) and boulders (45 cm) scattered among the finer material found in riffles and rapids.

Saunders and Gee (1964) studied the habitats utilized by underyearling and yearling salmon and their movements during the summer, fall and early winter. These authors reported that yearling parr selected either riffles or pools as "homes" and tended to remain in their respective habitats. While the authors were unable to study movements or young salmon during severe freshets they did find that young salmon moved from shallow riffles to nearby pools when water levels fell to seasonal lows. When freshets occurred and depth in the riffles was restored, individuals returned to their "home" habitat. Saunders and Gee (1964) reported that parr densities in the pools were similar to those in the well-populated riffle habitats. Consequently, they concluded that, in instances where brook trout were absent or were present at low population densities, pools were as suitable habitats for salmon parr as riffles. The authors also reported that although fry or underyearlings were numerous in shallow riffles during the summer, in autumn they became scarce in these areas but were found in greater numbers in the deeper riffles and pools already occupied by parr. In the fall, fry and parr were taken only from protected areas such as overhanging stream banks, among large rocks and under the sides of boulders and not in their summer "homes". The authors suggested several possible explanations for this: parr were lodged in the gravel below the surface of the streambed in preparation for overwintering; parr may have moved to other parts of the river for wintering or in response to the presence of large spawning salmon; ripe male parr may have moved to areas where adults were spawning (Jones and King 1948), or parr may have moved downstream as a fall migration (Meister 1962).

Symons and Heland (1978) studied the distribution of underyearlings, yearlings and older salmon in various substrates and water velocities. The authors observed in laboratory experiments that underyearling Atlantic salmon (less than 7 cm total length) chose shallow (10 - 15 cm), pebbly (1.6 - 6.4 cm diameter) riffles. As underyearlings grew (over 6.5 cm), their preferences for deeper and swifter parts of the riffles increased and by the time they reached 8 - 9 cm in length, 80 - 90% chose cobble and boulder (greater than 25.6 cm diameter) habitats with maximum riffle depths of 30 cm or greater. Yearlings (greater than 10 cm) reduced the number of underyearlings (less than 6 cm) found in these deeper habitats by chasing and occasionally eating them. Yearlings or older salmon did not inhabit riffles shallower than 20 cm where there were no boulders; the proportion of underyearlings to yearlings decreased as depth increased between 20 and 40 cm. This size - dependent behavior could explain the marked reduction in segregation of underyearlings and yearlings in the fall compared with their distribution in riffles and runs, respectively, in summer (Jones 1975) as well as the movement of underyearlings from shallow to deeper riffles in the autumn noted by Saunders and Gee (1964). Although underyearlings and yearling or older Atlantic salmon

inhabited areas with water velocities between 20 - 75 cm/s the highest densities were found in velocities of 50 - 65 cm/s according to Symons and Heland (1978).

In the Mad River, New Hampshire, Knight and Greenwood (1981) reported that underyearling (0+) parr inhabited stream sections where water velocity was 1.8 - 32.3 cm/s (mean velocity 13.9 cm/s) and water depth was 9 - 39 cm. Older parr (1+) appeared to prefer areas where water velocity ranged from 14 - 32.3 cm/s (mean velocity 20.3 cm/s) and water depth ranged from 15 - 40 cm (mean depth 29 cm). Knight and Greenwood (1981) reported that niches within the stream normally occupied by age 1+ and older parr may also be occupied by the age 0+ parr if the older parr are present in limited numbers or absent from that portion of the stream reach.

A comparison of riffle/run nursery habitat characteristics for underyearling (0+) and yearling parr (1+) described by different authors is summarized in Table 12.

Pools appear to act as suitable staging and rearing areas for juvenile salmon during low water conditions and may be as suitable as riffle areas for rearing yearling salmon. Pools also play an important role for adult salmon and can be categorized as "resting" or "holding" pools depending on their characteristics. Resting pools provide temporary refuges for adult salmon during their spawning migration. These pools usually lack adequate cover, temperature regime and depths needed for holding salmon but do provide staging areas where salmon weighing 2.7 kg or more can rest away from the swift current in lower water velocities, usually less than 61 cm/s (Elson 1975). In contrast, holding pools provide the necessary cover such as large boulders, logs, ledge outcroppings, surface turbulence or stream bank vegetation, and water depths of at least 1.8 m, lower water velocity usually less than 50 cm/s and lower water temperatures where salmon can hold for long periods of time during low stream flow conditions. Many of the major holding pools in the West, North and Main Branches of the LaHave River are outlined in Figure 9.

The role which stillwaters, flats and lakes play in rearing parr and subsequent smolt production has not been adequately studied. In Newfoundland, shallow lakes and ponds play a significant role in smolt production in certain streams (Pepper 1976). In the LaHave River where the lakes are deeper, lakes may act as staging areas during certain periods such as low summer flows or for overwintering rather than being utilized as significant nursery areas for young salmon. On the other hand, stillwaters and flats probably can be utilized, although less suitably, as nursery habitat.

Nursery habitat as described in this report refers to aquatic habitat utilized by the older stages of underyearling parr (0+) and yearling parr (1+) stages. In attempting to quantify various qualitative differences in parr nursery habitat, the authors examined parr densities found in different substrates studied over a six year period. "Good" parr nursery habitat was located in stream areas where the cobble/boulder substrate was equal to or greater than 50% of the stream section and where cobble made up at least 20% of this

substrate mixture; at least 70% of the stream section consisted of riffle and run. "Fair" parr nursery habitat was located in stream sections where the combined cobble/boulder composition ranged from 10 - 49% with a minimum of 10% cobble in the substrate mixture; at least 50% of the stream section consisted of riffle and run. These habitats are usually considered as traditional nursery areas and appear to be the major rearing sites for young salmon. "Marginal"rearing habitats consisted of stream sections where the combined cobble/boulder composition was less than 10% or where the stream consisted of pools, flats, stillwaters, or lakes. The role of these latter types of habitat is poorly understood; however, their role in rearing young salmon, while variable between streams, is thought to be significant for rivers such as the LaHave and Medway (Wykes 1967). For example, salmon anglers often observe or hook salmon parr in pools or deep runs. However, because of the difficulty of sampling deep water with existing electrofishing equipment, juvenile assessments have traditionally not sampled such habitats. Methodologies should be designed to enable future investigation of juvenile salmon utilization of these habitats so as to better understand the rearing potential of the LaHave River.

The potential Atlantic salmon parr nursery habitat measured during stream surveys carried out from 1976-81 is summarized in Table 13. The greatest potential parr nursery habitat was found on the Main Branch of the LaHave River. A total of 870,854 m^2 of good and 295,065 m^2 of fair nursery habitat were observed on this Branch; this habitat accounted for 60.4% of the total good and fair habitat found in the LaHave River. Other habitat types capable of rearing juvenile salmon parr in the Main Branch were as follows: marginal stream (74,292 m^2), flats (184,706 m^2), stillwater (1,077,719 m^2), pools (166,867 m^2) and 33 lakes with a total surface area of 1559.6 hectares.

The potential parr nursery habitat recorded in the West Branch of the LaHave River is summarized in Table 13. The West Branch contains 46,445 m^2 of good parr nursery habitat and 89,230 m^2 of fair parr nursery habitat. In addition, 26,875 m^2 of marginal stream, 102,044 m^2 of flats, 15,316 m^2 of stillwater, 5,907 m^2 of pools, and 22 lakes with a surface area of 1407 hectares may also be utilized for rearing young salmon. In terms of good and fair habitat, the West Branch contains roughly 7.0% of the total good and fair parr nursery habitat found in the LaHave River.

The Ohio River, an acidic tributary, accounts for 104,095 m^2 of good habitat and 84,612 m^2 of fair nursery habitat or 9.8% of the total potential parr nursery habitat classified as good and fair in the LaHave River (Table 13). In addition, 15,241 m^2 of marginal stream, 85,763 m^2 of flats, 166,701 m^2 of stillwater, 52,118 m^2 of pools and 12 lakes with a total surface area of 779.8 hectares were found in the Ohio River.

A total of 73,609 m^2 of good and 47,316 m^2 of fair parr nursery habitat were found in the North River (Table 13) - this represents 6.3% of the total good and fair potential parr nursery habitat found in the LaHave River. Other habitats potentially capable of rearing young salmon were measured in the North River

as follows: marginal stream (29,200 m^2), flats (79,095 m^2), stillwater (598,547 m^2), pools (69,204 m^2) and 14 lakes with a total surface area of 800 hectares.

The potential parr nursery habitat in the North Branch (Table 13) indicates that 234,832 m^2 of good and 84,467 m^2 of fair habitat exists in this tributary. In addition 23,675 m^2 of marginal stream, 163,770 m^2 of flats, 776,422 m^2 of stillwater, 80,647 m^2 of pools and 37 lakes with a total surface area of 2969.1 hectares was recorded which may be utilized for rearing. Excluding other habitat types, good and fair (319,299 m^2) nursery habitat accounts for 16.5% of the total good and fair type habitats in the LaHave River.

The uneven distribution of Atlantic salmon spawning and nursery habitat in some streams and the limited dispersal of underyearling salmon above and below potential spawning areas (Elson 1975; Symons 1969) may prevent the full utilization of available nursery areas. Using Elson's (1975) dispersal data, the potential nursery areas measured during the habitat surveys were reviewed relative to available spawning habitat in proximity to nursery habitat to calculate parr nursery habitat utilization. Table 14 summarizes the results of an interpretative analysis of these habitat data to determine the amount of nursery habitat which would normally be utilized under natural conditions in the LaHave River system.

The reduction from potential nursery area to utilizable nursery area for different types of habitat in the LaHave River varied, as follows: good nursery habitat (0.7%); fair nursery habitat (3.4%) and marginal nursery habitat (54.3%). Atlantic salmon production can then be calculated from data interpreted as utilizable in order to determine self-sustained production for the river. This production could be increased by the annual stocking of hatchery reared underyearling parr (0+) (e.g. fall fingerlings) in areas unutilized by wild salmon because of a lack of suitable spawning habitat in proximity to these nursery areas.

The spawning to nursery habitat ratio for each tributary and stream section is summarized in Table 15. While it is difficult to predict an ideal ratio since stock composition and stream productivity would influence stream utilization, stream sections such as Lake Paul Brook, Lake Torment to Tomahawk Lake, Tidehead to Wentzells Lake and Mason Meadow Brook might be expected to have lower yields because of the scarcity of spawning habitat. Juvenile production would also be adversely influenced by partial obstructions preventing full access of adult spawners to certain streams, by stream acidity conditions in certain tributaries such as the Ohio River, and by low water conditions in certain years

SUMMARY AND CONCLUSIONS

The LaHave River system has an estimated drainage area of 1668 km^2 including the estuary feeder streams. It has five major tributaries, Main Branch, West Branch, North Branch, Ohio River and North River and over 113 lakes with a total surface areas of 7516 hectares. The drainage basin lies in sedimentary rocks of the late Precambian known as the Meguma or gold-bearing group. The upper basin originates in Plutonic rocks consisting of monzo-granite and granodiorite, hard rocks which yield water of low conductivity. The river is relatively clean except for a minor sewage disposal problem at New Germany, and sewage and industrial pollution at Bridgewater with heavy metals. The latter problem requires study to determine the exact source of heavy metal pollution and what, if any, effects these are having on aquatic organisms in the estuary. Several fish passage problems still exist on Sixty Brook, North River, West Branch and the North Branch. These problems which consist largely of partial natural obstructions should be investigated with appropriate recommendations made for remedial action.

The LaHave River is a good salmon stream with an average gradient; its five major tributaries have the following stream gradients: Main Branch (2.64 m/km), West Branch (1.91 m/km), North Branch (4.99 m/km), Ohio River (6.52 m/km) and North River 4.01 m/km).

The LaHave River, excluding the West Branch and small feeder streams entering the estuary, has a mean monthly stream discharge ranging from 344.1 cfs to 2439.9 cfs. Low monthly flows occur in July (390.7 cfs), August (443.6 cfs) and September (344.1 cfs) while peak flows were recorded in December (2071.9 cfs), March (2120.2 cfs) and April (2439.9 cfs.) General flooding occurs when daily discharge exceeds 11,000 cfs, the estimated maximum channel capacity., An 80% probability exists for general flooding once in every five years. Low flows during the summer are common; there is an 80% probability that daily discharges of 20 cfs will occur once in every five years.

Stream temperatures of 7°C or greater occur for approximately 182 days from May to October each year. Although stream temperatures occasionally reach the upper lethal level for salmon (28 - 29°C), this usually occurs for a short period and overnight cooling reduces thermal stress. Mortalities have not been observed during the eight year study period (1973-81) which could be attributed to thermal stress. The temperature regime in the LaHave River appears to favour excellent juvenile salmon growth since the majority of smolts are two years of age at emigration.

Acidic streams with a pH less than 5.0 at critical periods include the Ohio River and Bob and John Brook (North River). The Main Branch at West Northfield has an annual pH range of 5.2 - 6.6. Consideration should be given to stream acidity control on the Ohio River if the full production potential of this major tributary is to be achieved. In addition, stream productivity is probably reduced by the generally soft waters found in the LaHave River.

Atlantic salmon spawning habitat was classified into two types: good and marginal. A total of 1,032,984 m^2 of spawning habitat was found in the LaHave River system; 35.6% of this total was classified as good spawning habitat. In terms of good spawning habitat, the Main Branch ranks first (132,732 m^2) followed by the North Branch (107, 845 m^2), Ohio River (55,086 m^2), West Branch (51,935 m^2) and the North River (20,518 m^2).

Atlantic salmon parr nursery habitats were classified as good, fair and marginal habitats consisting of pools, flats, stillwaters and rough stream sections. Since the distribution of spawning and nursery habitat was less than ideal in certain stream sections, calculations were made to convert rearing area from potential nursery recorded during the habitat surveys to utilizable nursery area. This resulted in a significant reduction in mostly poorer quality habitat - good (0.75%); fair (3.4%); marginal (54.3%). The total utilizable parr nursery habitat found in the LaHave River was estimated as 3,634,211 m^2; good and fair nursery habitat accounted for 62.6% of this total - the remaining nursery area is considered marginal but capable of rearing juvenile salmon. Utilizable habitat classified as "good" and "fair" parr nursery was distributed as follows: Main Branch (1,326,423 m^2), North Branch (399,946 m^2), Ohio River (236,907 m^2), North River (177,829 m^2) and the West Branch (135,095 m^2). The spawning/nursery ratio was 0.28 for the LaHave River system.

In conclusion, the LaHave River has an abundance of spawning and nursery habitat for juvenile salmon. It has adequate refuges in the form of resting/holding pools or lakes for juvenile and adult salmon during low flows. The limiting factors which adversely impact on Atlantic Salmon production are: minor obstructions of fish passage; acidic conditions in the Ohio River, Bob Brook and John Brook; and low stream productivity because of the soft waters found in the LaHave basin.

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Table 1. Mean length, width, drainage area and gradient of various tributaries of the LaHave River.

Tributary	Meander length (km)	Drainage Area (km^2)	Average Width (m)			Average Gradient (%)
			Mouth	Mid-length	Headwaters	
Estuary	17.6	155	-	-	-	-
West Branch	34.9	178	22.3	14.6	12.5	0.19
North Branch	52.5	453	20.0	18.2	5.1	0.49
Main Branch	74.4	490	55.7	14.5	8.3	0.26
Ohio River	38.0	190	13.5	14.6	12.0	0.65
North River	41.0	188	18.5	12.7	4.5	0.40

Table 2. Stream gradients in various tributaries and reaches of the LaHave River.

Tributary	Stream Section Description	Elevation (m)	Stream Section Lt (m)	Gradient (%)
West Branch	Main Branch to Hirtle Lake	54	28,200	0.191
North Branch	Wentzells Lake to Indian Lake	53	10,200	0.520
	Indian Lake to Sherbrooke Lake	38	9,300	0.409
	Sherbrooke Lake to Headwaters Sherbrooke River	76	14,000	0.543
	Lake Paul Brook	18	6,300	0.286
	Gully River	94	11,300	0.832
	Forty River	91	15,500	0.587
	Sand Brook	29	11,000	0.264
Ohio River	New Germany Lake to West Lake	70	8,400	0.833
	West Lake to Headwaters West River	37	8,000	0.463
	Little River	80	7,100	1.127
North River	Main Branch to Lake Torment	109	18,300	0.596
	Lake Torment to Tomahawk Lake	35	17,600	0.199
	Nimchin Brook	31	5,300	0.585
Main Branch	Tidehead to Wentzells Lake	31	12,000	0.258
	Wentzells Lake to Morgan Falls	10	9,600	0.104
	Morgan Falls to Cloud lake	136	45,400	0.300
	Mason Meadow Brook	91	11,300	0.805
	Sixty and Crossburn Brooks	85	13,000	0.654
	Thirty Brook	40	7,400	0.541
	Spry River	26	3,200	0.813
	Shellcamp Stream	73	14,500	0.503

Table 3. Summary of mean monthly discharge (cfs) above Morgan Falls on the LaHave River, 1970-79.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1970	443	885	392	1460	669	482	94.8	360	256	770	1030	616
1971	474	1890	1070	2290	1230	375	44.7	546	166	215	700	1170
1972	1250	680	1890	1270	2380	398	208	79.8	31.8	817	1860	1290
1973	986	1050	1450	1050	1050	994	696	699	134	41.1	483	1530
1974	751	1220	1590	1170	499	464	159	99.8	573	1430	1160	1390
1975	974	332	1150	1900	680	370	41.8	33.0	23.0	334	999	1770
1976	1530	1700	1210	1140	1190	168	401	115	170	815	899	1530
1977	805	516	1360	1900	554	595	310	300	512	1790	998	1510
1978	2360	488	612	1600	466	179	47.1	14.2	13.2	130	159	560
1979	2090.6	1027.6	2468.5	-	-	-	-	-	-	-	-	-
$\bar{X}$	1166.4	978.9	1319.3	1531.1	968.7	447.2	222.5	249.6	208.8	704.7	920.9	1262.9
S.D.	649.23	515.06	596.41	424.40	605.61	246.43	217.74	243.99	206.11	600.09	472.30	418.18
Range	443-1530	332-1890	392-1890	1050-2290	466-2380	168-994	44.7-696	14.2-699	13.2-573	41.1-1790	159-1860	560-1770

Table 4. Summary of mean monthly discharge (cfs) at West Northfield on the LaHave River, 1970-80.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1970	921	1230	632	2200	1190	936	209	641	515	1330	1650	1120
1971	813	3180	1800	3710	2130	768	120	901	369	376	1040	1920
1972	2030	1230	3100	2110	4090	859	452	168	65.2	1040	3000	2250
1973	1650	1790	2270	1790	1690	1590	1260	1200	265	87.5	758	2370
1974	1280	1970	2660	1950	820	[illegible]	311	162	825	2490	1870	2360
1975	1620	599	1840	2990	1230	676	146	69.6	47.4	511	1510	3020
1976	2550	2690	1920	1860	1880	345	562	265	297	1190	1480	2340
1977	1370	885	2190	3000	947	992	562	509	720	2770	1590	2430
1978	4040	899	903	2610	852	300	107	45.8	27.8	167	244	835
1979	3312.5	1878.7	4061.1	1956.4	1289.0	1059.4	279	822.8	618	1239.5	2807.5	1772.8
1980	1108.9	307.2	1945.8	2662.7	907.6	388.5	289.6	95.4	35.3	250.7	1447.9	2373.1
$\bar{X}$	1881.4	1514.5	2120.2	2439.9	1547.8	792.7	390.7	443.6	344.1	1041.1	1581.6	2071.9
S.D.	1028.71	883.43	948.35	608.84	949.37	373.15	330.73	396.85	291.05	908.57	799.80	627.84
Range	813-4040	307.2-3180	632-4061.1	1790-3710	820-4090	300-1590	107-1260	45.8-1200	27.8-825	87.5-2770	244-3000	835-3020

Table 5. Monthly ranges in mean daily water temperatures in various tributaries of the LaHave River.

TRIBUTARY	RANGE IN MEAN DAILY WATER TEMPERATURE (°C)						
	May	June	July	Aug.	Sept.	Oct.	Nov.
Main Branch - Morgan Falls	7.1- 19.3	16.0- 20.5	20.3- 23.1	20.7- 23.1	13.8- 20.6	6.2- 14.1	
Ohio River		17.3- 21.8	17.7- 25.1	17.0- 24.1	10.6- 22.4	5.1- 11.5	0.7- 5.2
Sixty Brook			14.5- 22.5	16.0- 24.3	7.9- 22.3	6.0- 13.5	
North River		16.5- 22.3	17.8- 25.3		8.5- 21.3	5.3- 13.8	
North Branch - Indian Falls		15.9- 20.3		17.3- 24.4	13.0- 17.8	6.3- 14.9	
West Branch			14.0- 21.5			3.5- 10.8	

Table 6. Summary of pH and conductivity data collected in various tributaries of the LaHave River, July 1980.

Sampling location		Conductivity (uhmos/cm)	pH
Main LaHave River	Cookville	-	6.18
	Bridge at Dalhousie Falls	25.0	6.18
	Lower Thirty Lake	26.0	5.80
	Sixty Brook	19.0	5.96
	Lower Sixty Lake	21.0	6.05
	Crossburn Brook	24.5	5.58
	Twin Brooks	22.2	5.62
	Shell Camp Stream	24.0	5.90
	Mason Med. Brook	-	5.74
	N.R. Roop Brook	23.0	5.70
Ohio River	Simpson's Corner	21.0	5.30
	West Lake	21.0	5.30
	Little River	21.0	4.71
	Pleasant Lake	25.0	5.36
	West River	23.0	4.70
North River	Highway Bridge	21.5	6.05
	Peter Veinot Stillwater	23.0	5.80
	Bob & John Brook	23.0	4.90
	Lake Torment	22.0	6.00
	Lakeview	22.0	6.05
	Armstrong Lake	21.0	6.10
	Nimchin Brook	22.0	5.95
	Tomahawk Stream	31.0	6.31
	Dog Falls	—	—
West Branch	Little Wiles Lake	28.0	5.12
	Rhyno Lake	25.0	5.93
	Demones Run	24.0	5.82
	Smith Brook	25.0	5.43
	Hemford	25.0	6.02
North Branch	Pinehurst	-	6.05
	Forty River	28.0	5.55
	Gully River	21.0	5.15
	Sherbrooke River	21.0	5.70
	Lake Paul Brook	22.0	6.10

Table 7. Monthly variation in pH and conductivity in the Main Branch of the LaHave River at West Northfield.

MONTH	pH			Conductivity (umhos/cm)		
	1954-55[1]	1980	1981	1954-55[1]	1980	1981
January	6.4		5.6	27.8		35.0
February	6.2		5.2	25.0		32.0
March	5.7	6.0	5.8	26.3	37.0	32.0
April	6.3	5.8	5.4	25.5	31.0	27.0
May	6.3	5.8	5.6	26.2	29.0	29.0
June	-	6.1	6.1	-	28.0	28.0
July	6.7	6.0	5.8	25.4	30.0	33.0
August	6.1	6.3	6.0	26.1	28.0	32.0
September	6.7	6.6	6.2	28.5	31.0	51.0
October	6.1	6.3	6.1	31.7	34.0	39.0
November	5.8	5.7	5.6	27.5	44.0	28.0
December	5.9	5.6		27.4	39.0	

1. Sampled at the end of each month (Thomas 1960)

Table 8. Stream characteristics of ten good salmon spawning areas on the LaHave River.

Site Number	Substrate Composition (%)				Riffle (%)	Run (%)	Average Depth (cm)		Velocity[1] (cm/s)	Gradient (%)
	Sand	Gravel	Cobble	Boulder			Aug.	Oct.		
1	5	60	20	15	60	40	14.6	48.0	72.24	0.86
3	10	80	10	-	50	30	16.2	30.0	98.15	1.00
8	5	60	30	5	70	-	15.6	31.0	80.16	0.53
10	5	40	40	15	80	20	13.9	31.0	80.16	0.66
14	10	40	30	20	80	10	14.7	36.0	58.52	0.33
16	-	60	25	15	60	40	-	-	-	-
30	5	60	30	5	100	-	12.7	-	-	-
32	5	50	30	15	50	25	15.1	-	-	-
35	-	80	15	5	95	5	11.7	-	-	-
40	-	50	40	10	70	-	14.5	-	-	-
Mean	6.4	58.0	27.0	11.7	71.5	17.0	14.3	35.2	77.85	0.68
S.D.	2.44	13.98	9.78	5.59	17.33	16.19	1.40	7.53	14.386	0.265

1. Water velocity measurements, October 1981.

Table 9. Stream characteristics of five marginal salmon spawning areas on the LaHave River.

Site Number	Substrate Composition (%)					Riffle (%)	Run (%)	Average Depth (cm) Aug.	Velocity[1] (cm/s)	Gradient (%)
	Silt	Sand	Gravel	Cobble	Boulder					
12	-	5	5	20	70	-	80	54.0	91.14	0.73
21	-	20	30	20	30	50	30	18.8	-	-
38	-	10	10	20	60	10	90	41.0	91.14	0.70
39	-	10	20	40	30	50	20	18.1	-	-
41	-	5	20	20	55	20	80	19.7	-	-
Mean	-	10.0	17.0	24.0	49.0	32.5	60.0	21.0	91.14	0.72
S.D.	-	6.12	9.75	8.94	18.17	20.62	32.40	3.02	0.000	0.021

1. Water Velocity Measurements, October 1981

Table 10. Comparison of stream characteristics of spawning habitat as described by different authors, (mean values).

River Location	Source	Water Temperature During Spawning Activity (°C)	Water Depth (cm)	Water Velocity (cm/s)	Standard Permeabilities (K10-cm/s)
Maine	Jordan (1981)	7-10.5	22-74 (36)	27-83 (49)	1.2-78
New Brunswick	Peterson [1] (1978)	-	9-39 (20)	36-64 (52)	6.6-90
Nova Scotia	This Study	4-7	30-48 (35)	58-98 (78)	-

1. Measurements taken within one week of low flow conditions.

Table 11. Distribution of good and marginal Atlantic salmon spawning habitat in various tributaries of the LaHave River.

Tributary - Stream section description	Stream section gradient (m/km)	Spawning habitat (m^2)		
		Good	Marginal	Total
West Branch Main Branch to Hirtle Lake	1.91	51,935	73,241	125,176
North Branch Wentzells Lake to Indian Lake	5.20	36,675	85,519	122,194
Indian Lake to Sherbrooke Lake	4.09	56,675	39,263	95,938
Sherbrooke Lake to Headwaters Sherbrooke River	5.43	13,403	47,183	60,586
Lake Paul Brook	2.86	528	3,997	4,525
Gully River	8.32	564	5,216	5,780
Ohio River New Germany Lake to West Lake	8.33	45,021	70,144	115,165
West Lake to Headwaters West River	4.63	7,276	11,302	18,578
Little River	11.27	2,789	5,962	8,751
North River Main Branch to Lake Torment	5.96	18,170	47,529	65,699
Lake Torment to Headwaters	1.99	220	5,445	5,665
Nimchin Brook	5.85	2,128	2,670	4,798
Main Branch Tidehead to Wentzells Lake	2.58	37,033	23,636	60,669
Wentzells Lake to Morgan Falls	1.04	45,322	63,941	109,263
Morgan Falls to Headwaters	3.00	46,409	146,323	192,732
Mason Meadow Brook	8.05	970	8,698	9,668
Sixty and Crossburn Brooks	6.54	2,998	15,839	18,837
Thirty Brook	5.41	-	5,747	5,747
Spry River	8.13	-	3,213	3,213
TOTAL		368,116	664,868	1,032,984

Table 12 Comparison of stream characteristics of underyearling (0+) and yearling (1+) parr nursery habitat as described by different authors, (mean values).

River Location	Source	Water Depth (cm)	Water Velocity (cm/s)	Gradient	Substrate Diameter (cm)
Underyearling Parr (0+)					
New Hampshire	Knight and Greenwood (1981)	9-39	1.8-32.3 (13.9)	-	-
New Brunswick	Symons and Heland (1978)	10-15	20-75 (50-65)	-	Gravel (1.6-6.4)
Nova Scotia	This Study	17-25 (21)	-	.2-1.0 (.6)	Gravel (63%) (0.6-10.2)
Yearling Parr (1+)					
New Hampshire	Knight and Greenwood (1981)	15-40 (29)	14-32 (20)	-	-
New Brunswick	Symons and Heland (1978)	20-40 (30)	20-75 (50-65)	-	Cobble/Boulder (>25.6)
Nova Scotia	This Study	18.5-33 (25)	58.5-91 (76.5)[1]	0.1-2.9 (1.1)	Cobble/Boulder (67%)(10.4->30.6)

1. Water velocity measurements were taken in October and would presumably be higher than in comparable studies carried out in August - September.

Table 13. Potential Atlantic salmon nursery habitat in the LaHave River derived from stream inventory surveys, 1976-81.

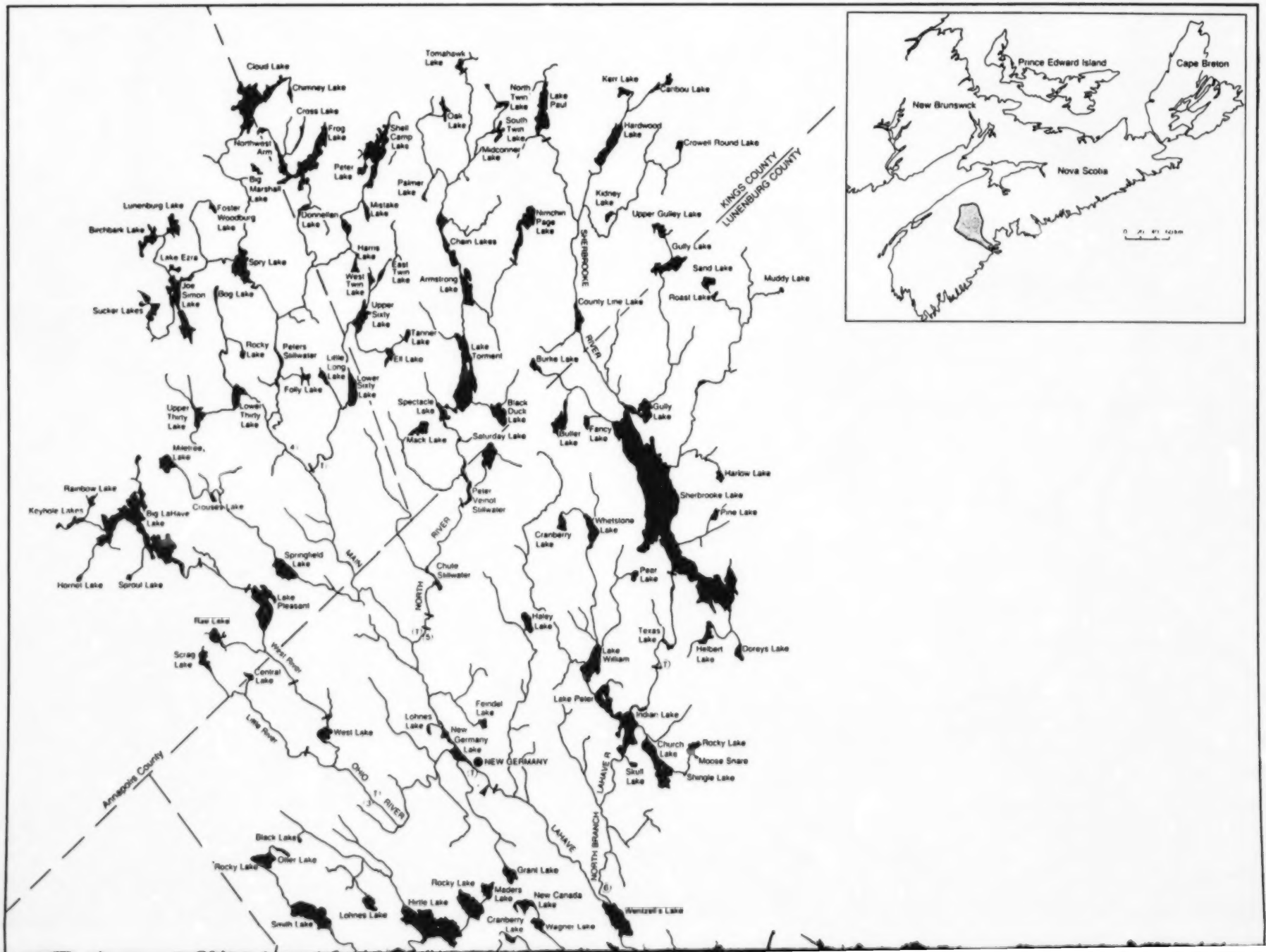
Tributary	Stream section description	Nursery habitat (m^2)					
		Good	Fair	Stream	Flats	Stillwater	Pools
West Branch	Main Branch to Hirtle Lake	46,445	89,230	26,875	102,044	15,316	5,907
North Branch	Wentzells Lake to Indian Lake	103,768	28,580	8,600	87,166	-	28,470
	Indian Lake to Sherbrooke Lake	56,376	43,908	11,456	58,558	180,612	22,749
	Sherbrooke Lake to Headwaters Sherbrooke River	62,859	11,354	2,950	10,251	492,250	19,001
	Lake Paul Brook	5,325	625	525	7,321	103,560	6,817
	Gully River	6,504	-	144	474	-	3,610
Ohio River	New Germany Lake to West Lake	74,935	61,647	14,361	64,175	63,440	32,410
	West Lake to Headwaters West River	21,565	18,570	880	19,130	96,776	11,012
	Little River	7,595	4,395	-	2,458	6,485	8,696
North River	Main Branch to Lake Torment	62,434	34,252	28,101	36,850	480,722	39,963
	Lake Torment to Headwaters	8,663	7,558	1,022	26,240	104,625	29,141
	Nimchin Brook	2,512	5,506	77	16,005	13,200	100
Main Branch	Tidehead to Wentzells Lake	575,170	117,845	35,433	-	104,378	37,422
	Wentzells Lake to Morgan Falls	78,588	57,958	425	70,035	69,800	15,035
	Morgan Falls to Headwaters	171,620	89,683	33,420	84,268	666,746	87,500
	Mason Meadow Brook	13,223	20,640	1,634	12,996	35,787	12,358
	Sixty Brook and Crossburn Brook	21,580	5,982	3,380	8,477	68,564	2,905
	Bog Brook	7,460	2,957	-	8,930	-	11,647
	Spry River	3,213	-	-	-	132,444	-
	TOTAL	1,329,835	600,690	169,283	615,378	2,634,705	374,743

Table 14. Estimated nursery habitat which could be naturally utilized by Atlantic salmon in the LaHave River system.

Tributary	Stream section description	UTILIZATION OF NURSERY HABITAT (m^2)					
		Stream section gradient (m/km)	Good	Fair	Marginal Stream	Estimated other habitats normally utilized	Total estimated utilized nursery habitat
West Branch	Main Branch to Hirtle Lake	1.91	45,095	84,093	22,915	115,445	267,548
North Branch	Wentzells Lake to Indian Lake	5.20	103,768	28,580	8,600	82,746	223,694
	Indian Lake to Sherbrooke Lake	4.09	56,376	43,908	11,456	232,319	344,059
	Sherbrooke Lake to Headwaters Sherbrooke River	5.43	62,859	11,354	2,950	86,542	163,705
	Lake Paul Brook	2.86	5,325	625	525	31,038	37,513
	Gully River	8.32	6,504	-	144	2,596	9,244
Ohio River	New Germany Lake to West Lake	8.33	74,095	58,569	12,011	134,835	279,510
	West Lake to Headwaters West River	4.63	21,565	18,570	880	43,685	84,700
	Little River	11.27	7,595	4,395	-	17,639	29,629
North River	Main Branch to Lake Torment	5.96	60,650	29,902	13,171	81,993	185,716
	Lake Torment to Headwaters	1.99	7,140	2,915	102	73,671	83,828
	Nimchin Brook	5.85	2,512	5,506	77	5,502	13,597
Main Branch	Tidehead to Wentzells Lake	2.58	575,170	117,845	35,433	141,800	870,248
	Wentzells Lake to Morgan Falls	1.04	78,588	57,958	425	85,070	222,041
	Morgan Falls to Headwaters	3.00	171,620	88,933	33,420	368,118	662,091
	Mason Meadow Brook	8.05	13,223	18,240	1,634	30,321	61,784
	Sixty Brook	6.54	21,580	5,982	1,028	51,832	80,422
	Thirty Brook	5.41	7,460	2,957	-	4,465	14,882
	Spry River	8.13	-	-	-		
	TOTAL		1,321,125	580,332	144,771	1,589,617	3,634,211

Table 15. Estimated utilization of salmon spawning and nursery habitat and Sp/Nu ratio in the LaHave River system.

Tributary	Stream section description	Stream section gradient (m/km)	Total estimated utilizable spawning habitat (Sp)(m^2)	Total estimated utilizable nursery habitat (Nu)(m^2)	Sp/Nu Ratio
West Branch	Main Branch to Hirtle Lake	1.91	125,176	267,548	0.47
North Branch	Wentzells Lake to Indian Lake	5.20	122,194	223,694	0.55
	Indian Lake to Sherbrooke Lake	4.09	95,938	344,059	0.28
	Sherbrooke Lake to Headwaters Sherbrooke River	5.43	60,586	163,705	0.37
	Lake Paul Brook	2.86	4,525	37,513	0.12
	Gully River	8.32	5,780	9,244	0.63
Ohio River	New Germany Lake to West Lake	8.33	115,165	279,510	0.41
	West Lake to Headwaters West River	4.63	18,578	84,700	0.22
	Little River	11.27	8,751	29,629	0.30
North River	Main Branch to Lake Torment	5.96	65,699	185,716	0.35
	Lake Torment to Headwaters	1.99	5,665	83,828	0.07
	Nimchin Brook	5.85	4,798	13,597	0.35
Main Branch	Tidehead to Wentzells Lake	2.58	60,669	870,248	0.07
	Wentzells Lake to Morgan Falls	1.04	109,263	222,041	0.49
	Morgan Falls to Headwaters	3.00	192,732	662,091	0.29
	Mason Meadow Brook	8.05	9,668	61,784	0.16
	Sixty and Crossburn Brooks	6.54	18,837	80,422	0.23
	Bog Brook	5.41	5,747	14,882	0.39
	Spry River	8.13	3,213	-	-
	TOTAL		1,032,984	3,634,211	0.28


Cloud Lake
Chimney Lake
Cross Lake
Frog Lake
Northwest Arm
Big Marshall Lake
Peter Lake
Shell Camp Lake
Tomahawk Lake
Oak Lake
North Twin Lake
South Twin Lake
Lake Paul
Midconnel Lake
Kerr Lake
Caribou Lake
Hardwood Lake
Crowell Round Lake
Palmer Lake
Kidney Lake
Upper Gulley Lake
KINGS COUNTY
LUNENBURG COUNTY
Lunenburg Lake
Foster Woodburg Lake
Birchbark Lake
Donnellan Lake
Mistake Lake
Nemchin Page Lake
SHEBROOKE
Gully Lake
Sand Lake
Muddy Lake
Lake Ezra
Spry Lake
Harris Lake
West Twin Lake
East Twin Lake
Chain Lakes
Armstrong Lake
Joe Smon Lake
Bog Lake
Sucker Lakes
Upper Sixty Lake
County Line Lake
Roast Lake
Tanner Lake
Rocky Lake
Peters Stillwater
Little Long Lake
Lake Torment
Burke Lake
RIVER
Eli Lake
Lower Sixty Lake
Folly Lake
Upper Thirty Lake
Lower Thirty Lake
Spectacle Lake
Black Duck Lake
Gully Lake
Butler Lake
Fancy Lake
Mack Lake
Saturday Lake
Mistree Lake
Harlow Lake
Rainbow Lake
Keyhole Lakes
Big LaHave Lake
Crousers Lake
Peter Vernot Stillwater
Sherbrooke Lake
Pine Lake
Whetstone Lake
Cranberry Lake
Springfield Lake
MAIN
RIVER
Chute Stillwater
Pear Lake
Hornet Lake
Sproul Lake
NORTH
Lake Pleasant
Haley Lake
Raw Lake
Texas Lake
Lake William
Helbert Lake
Doreys Lake
Scrag Lake
West River
Central Lake
Lake Peter
Fendel Lake
Lohnes Lake
Indian Lake
Annapolis County
Lake River
West Lake
New Germany Lake
Church Lake
Rocky Lake
Moose Snare
Shingle Lake
NEW GERMANY
OHIO
RIVER
Skut Lake
LAHAVE R
Black Lake
Otter Lake
Rocky Lake
LAHAVE
NORTH BRANCH
Grant Lake
Rocky Lake
Maders Lake
New Canada Lake
Hirtle Lake
Lohnes Lake
Cranberry Lake
Wagner Lake
Wentzell's Lake
Smith Lake
Prince Edward Island
Cape Breton
New Brunswick
Nova Scotia

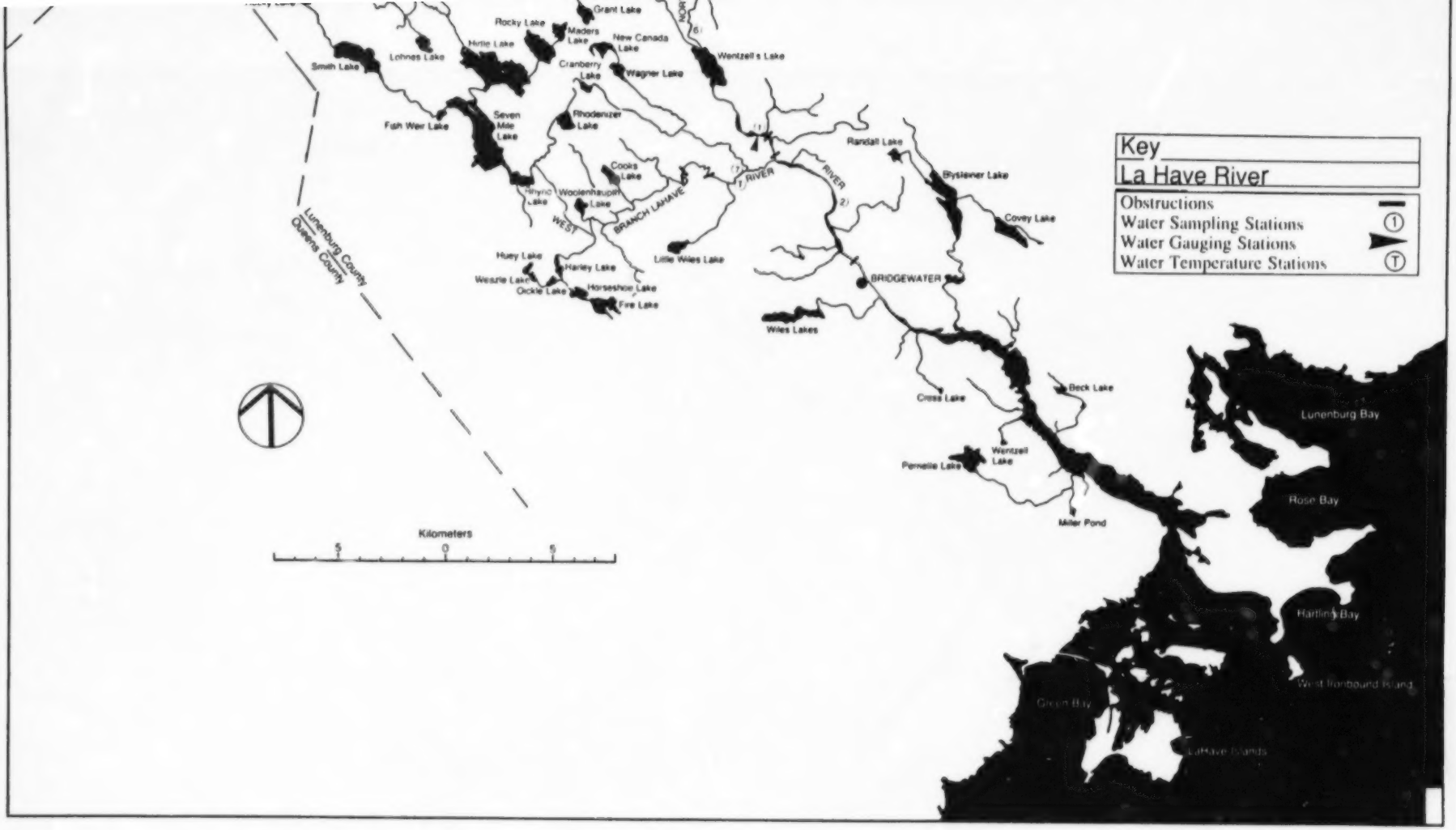


Fig. 1. Map of the LaHave River watershed showing locations cited in the text.

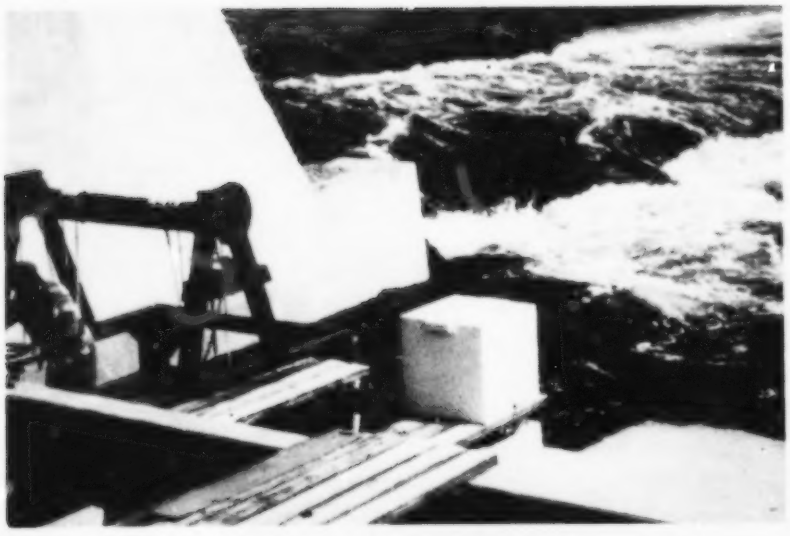


Fig. 2 Morgan Falls fishway and trapping facilities used to identify and count anadromous and catadromous fish.

Fig. 3 Photographs of Indian Falls on the North Branch of the LaHave River and the modified fishway used to pass anadromous fish.

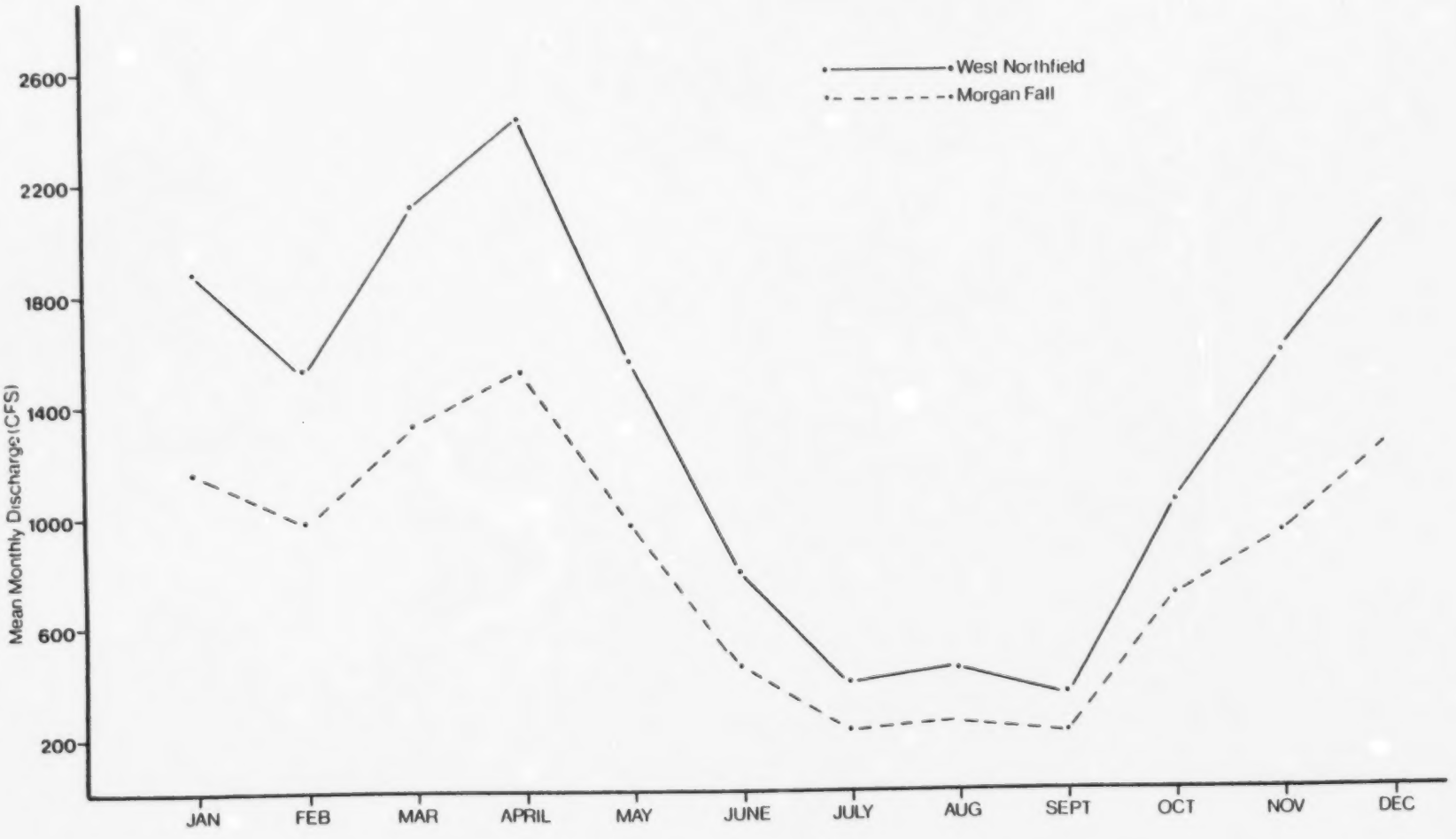


Fig. 4. Mean monthly discharge (cfs) at the Morgan Falls and West Northfield water guaging stations.

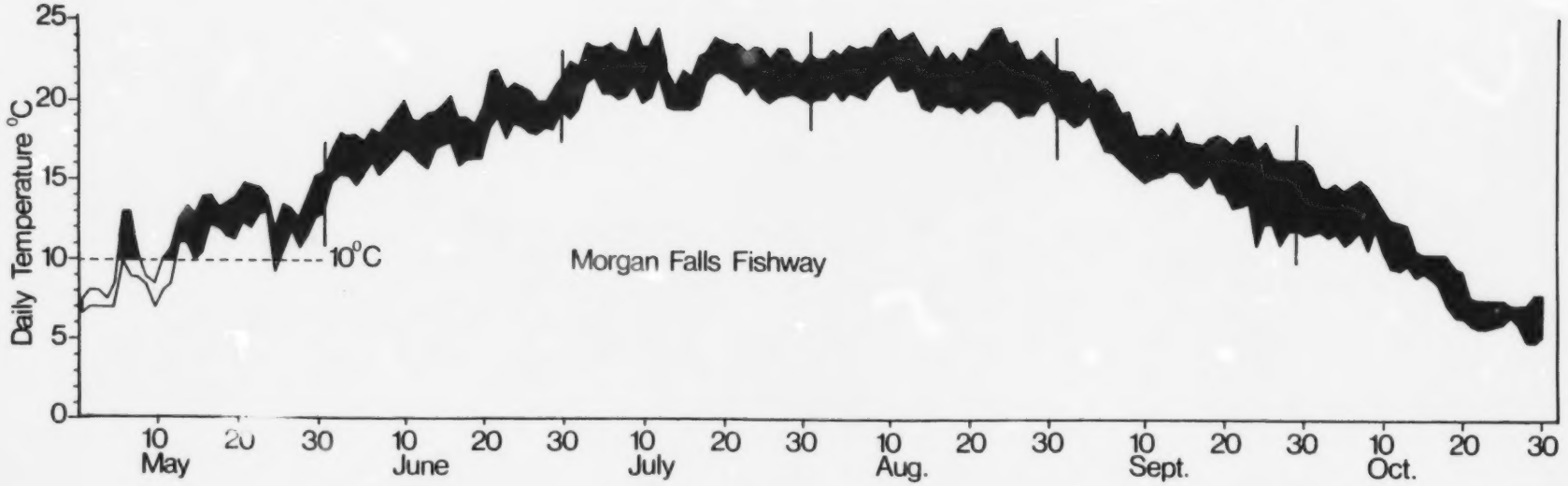


Fig. 5. Mean daily maximum and minimum water temperatures (°C) during 1972-74 and 1976-77.

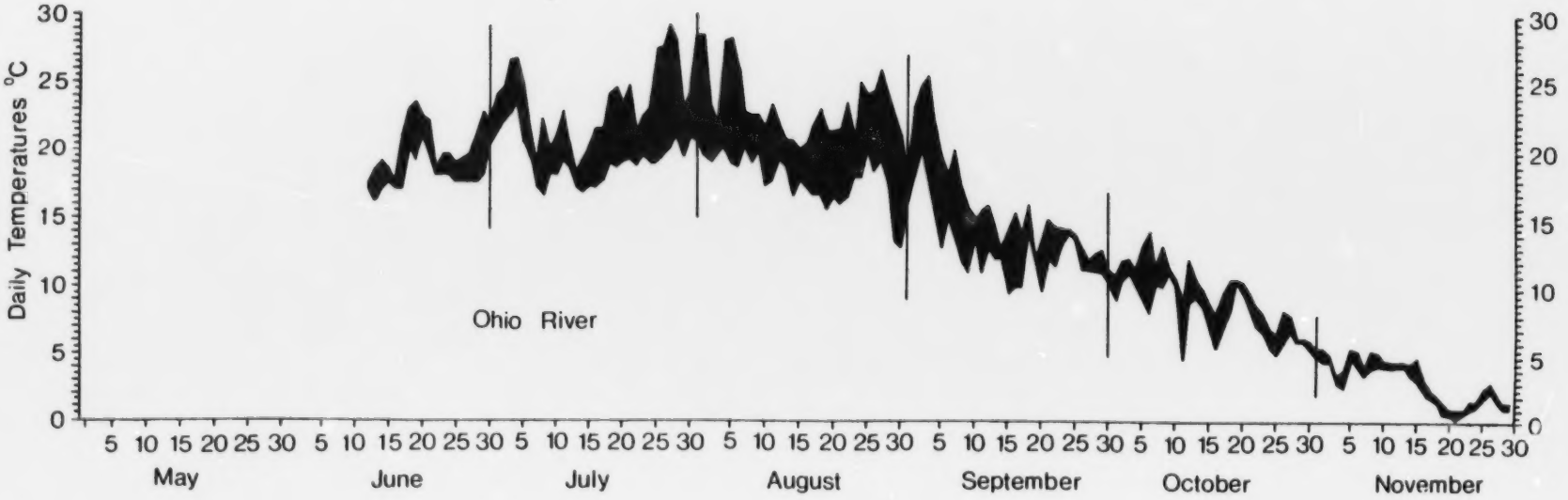


Fig. 6. Mean daily maximum and minimum water temperatures (°C) recorded in the Ohio River, 1980-81.

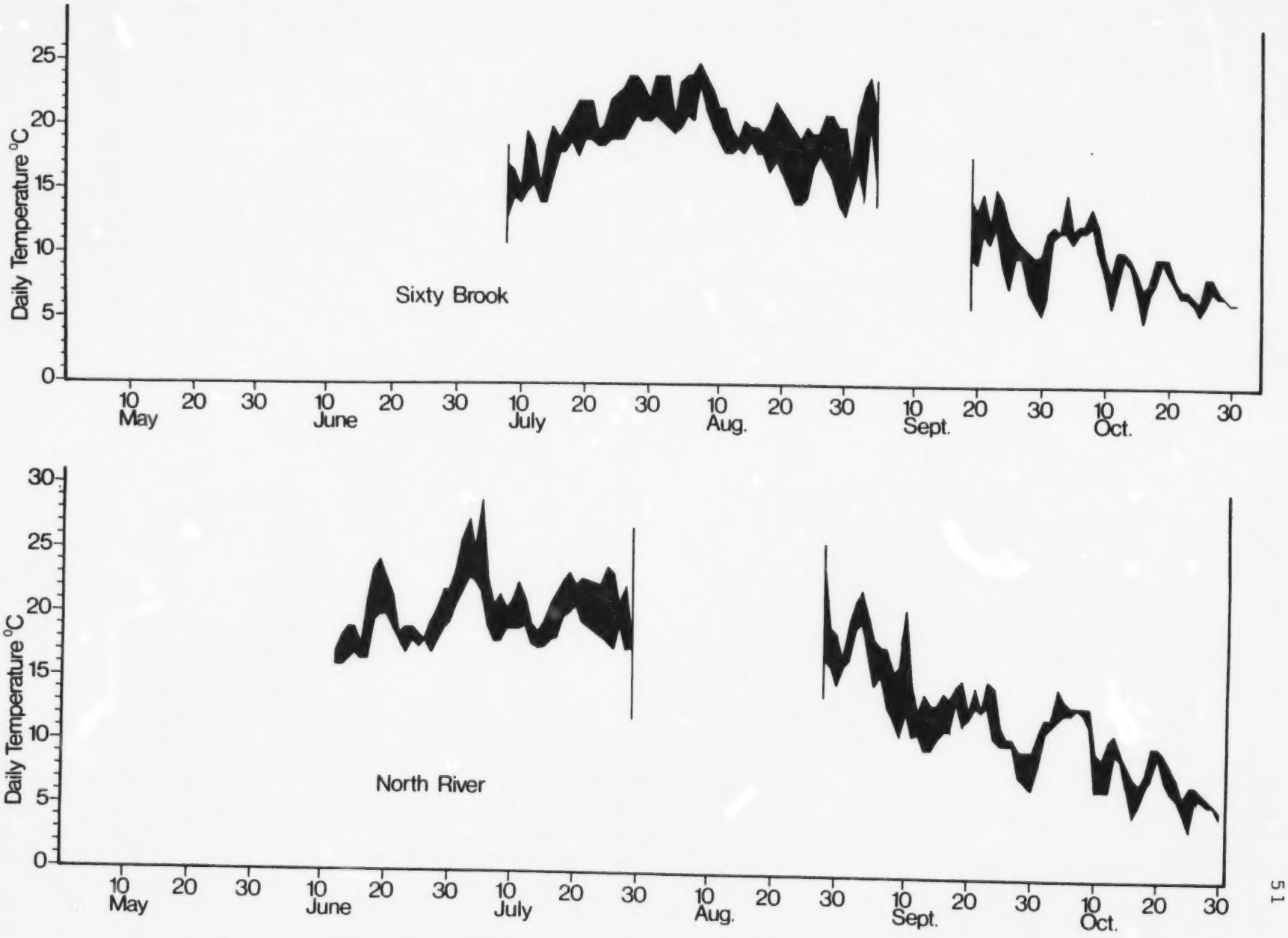


Fig. 7. Mean daily maximum and minimum water temperatures (°C) recorded in Sixty Brook and in the North River, 1980-81.

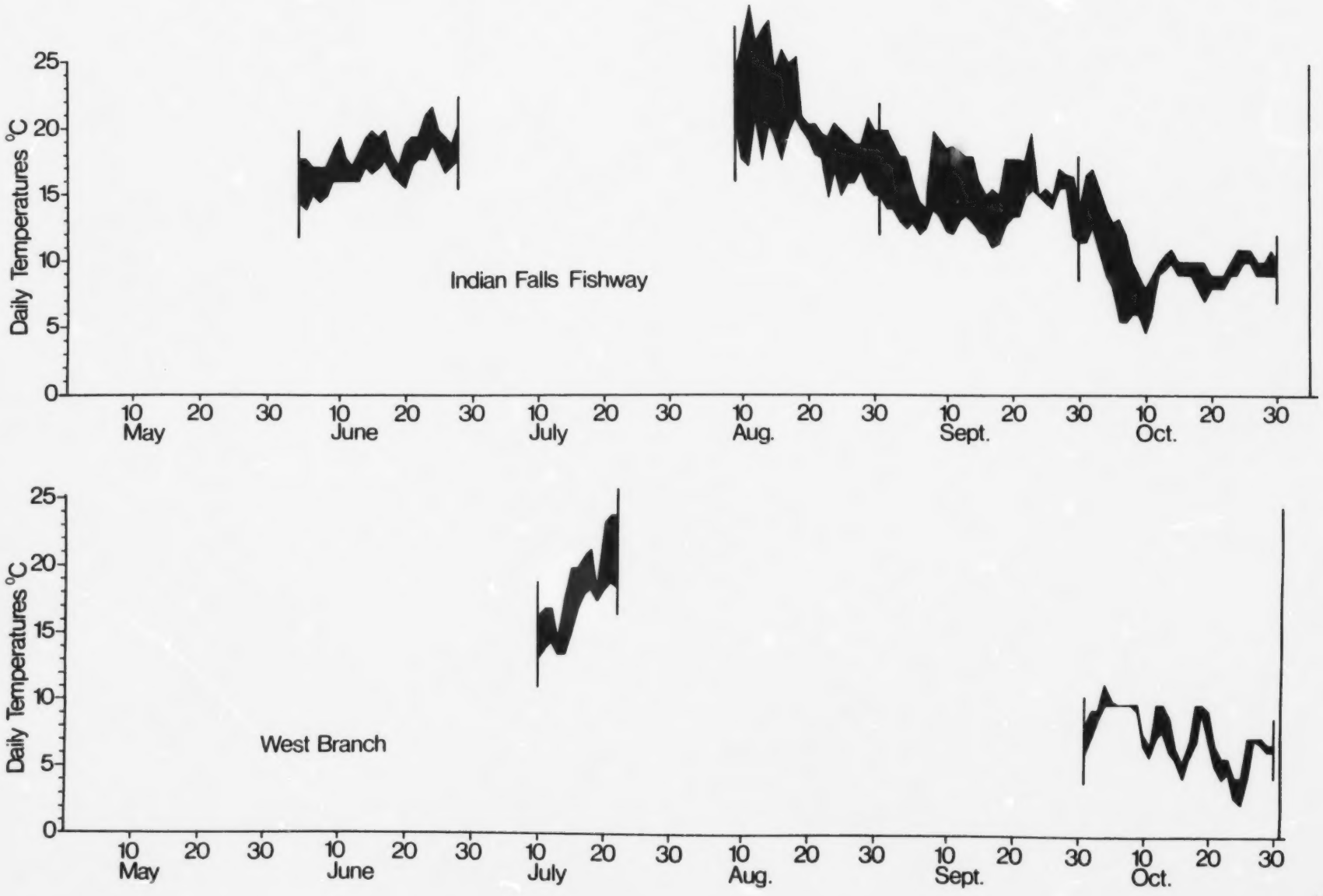


Fig. 8. Mean daily maximum and minimum water temperatures (°C) recorded in the North and West Branches of the LaHave River, 1975-76 and 1981 respectfully.

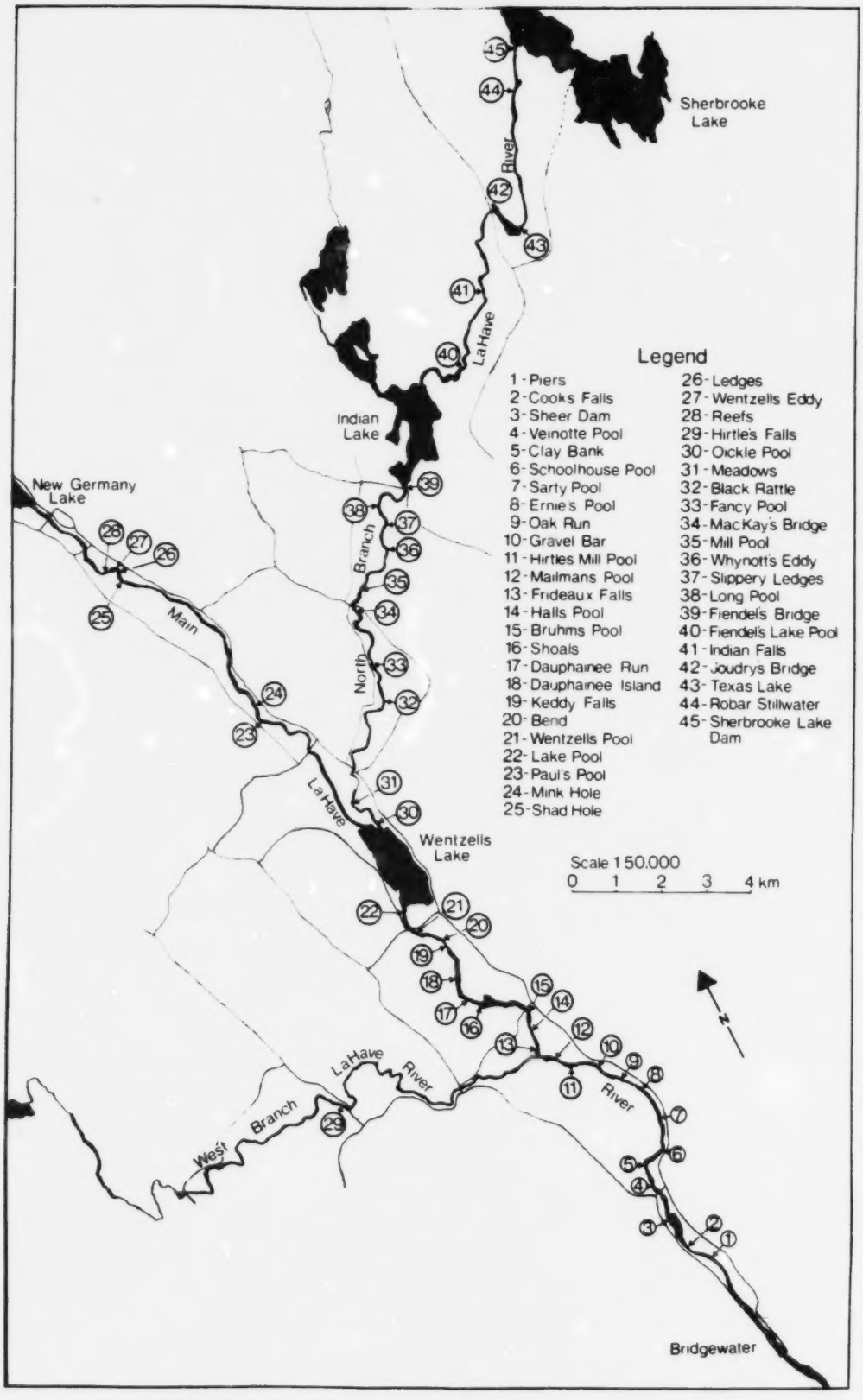


Fig. 9. **Location of the major salmon holding pools in the LaHave River.**

APPENDIX 1. Freshwater lakes in the LaHave River drainage basin and their estimated surface area

Lake		Surface area (Hectares)
West Branch	Cranberry Lake	14.4
	Wagner Lake	28.8
	New Canada Lake	40.3
	Little Wilea Lake	30.0
	Cook Lake	30.4
	Wollenhaupt Lake	23.8
	Harley Lake	21.5
	Unnamed Lake	7.8
	Horseshoe Lake	24.0
	Fire Lake	56.8
	Weazle Lake	12.1
	Huey Lake	12.6
	Rhodenizer Lake	40.6
	Rhyno Lake	35.8
	Seven Mile Lake	285.9
	Fish Weir Lake	13.1
	Smith Lake	160.4
	Rocky Lake	59.7
	Hirtle Lake	336.9
	Rocky Lake	105.2
	Hader Lake	31.9
	Haines Lake	35.0
North Branch	Indian Lake	137.9
	Skull Lake	8.7
	Church Lake	155.4
	Shingle Lake	3.2
	Rocky Lake	26.6
	Moose Snare Lake	3.1
	Lake Peter	79.6
	Lake William	100.9
	Whetstone Lake	60.2
	Cranberry Lake	25.1
	Pear Lake	15.5
	Texas Lake	13.4
	Sherbrooke Lake	1449.2
	Holbert Lake	35.8

Lake		Surface area (Hectares)
		20.1
North Branch (Cont'd)	Doreys Lake	15.4
	Pine Lake	15.5
	Harlow Lake	6.8
	Roast Lake	28.0
	Sand Lake	8.4
	Muddy Lake	69.3
	Gully Lake	86.9
	Gully Lake	29.6
	Upper Gully Lake	26.2
	Crowell Lake	31.7
	County Line Lake	120.1
	Lake Paul	7.8
	Kidney Lake	13.8
	Crowell Round Lake	108.9
	Hardwood Lake	21.5
	Kerr Lake	31.7
	Caribou Lake	15.5
	Franey Lake	65.2
	Butler Lake	18.9
	Burke Lake	2.3
	Haley Lake	72.5
	New Germany Lake	38.4
	Grant Lake	10.2
Ohio River	Central Lake	34.5
	Scrag Lake	38.4
	West Lake	36.4
	Rae Lake	185.0
	Lake Pleasant	416.4
	Big LaHave Lake	6.6
	Sproul Lake	8.4
	Unnamed Lake	5.2
	Hornet Lake	16.5
	Keyhole Lake	13.8
	Rainbow Lake	8.4
	Lohnes Lake	

Lake		Surface area (Hectares)
North River	Saturday Lake	63.1
	Mack Lake	37.6
	Otter Lake	32.9
	Lake Torment	250.8
	Black Duck Lake	63.2
	Armstrong Lake	89.5
	Nimchin Page Lake	107.2
	Chain Lake	78.5
	Palmer Lake	9.1
	Midconner Lake	4.9
	South Twin Lake	27.2
	North Twin Lake	17.3
	Oak Lake	7.5
	Tomahawk Lake	11.2
Mason Meadow Brook	Springfield Lake	87.6
	Crouses Lake	6.3
	Miletree Lake	49.5
Sixty Brook	Little Long Lake	20.1
	Lower Sixty Lake	70.7
	Upper Sixty Lake	64.8
	East Twin Lake	12.0
	West Twin Lake	13.4
	Ell Lake	19.9
	Tanner Lake	12.3
Thirty Brook	Lower Thirty Lake	43.7
	Bog Lake	10.5
	Rocky Lake	8.7
	Upper Thirty Lake	35.5
	Folly Lake	8.9
Spry River	Spry Lake	99.4
	Lunenburg Lake	39.7
	Joe Simon Lake	146.0
	Birchbark Lake	43.9
	Sucker Lake	41.3

	Lake	Surface area (Hectares)
Spry River	Big Marshall Lake	12.3
	Little Marshall Lake	8.3
	Cloud Lake	210.3
	Lily Lake	2.1
	Chimney Lake	9.2
Shell Camp Stream	Donnellan Lake	15.5
	Frog Lake	167.1
	Northwest Arm Lake	63.5
	Cross Lake	15.7
	Harris Lake	13.8
	Mistake Lake	16.7
	Shell Camp Lake	172.4
	Peter Lake	18.5